Volume 30 SEPTEMBER, 1946 Number 9

BULLETIN
of the
American Association *of* Petroleum Geologists

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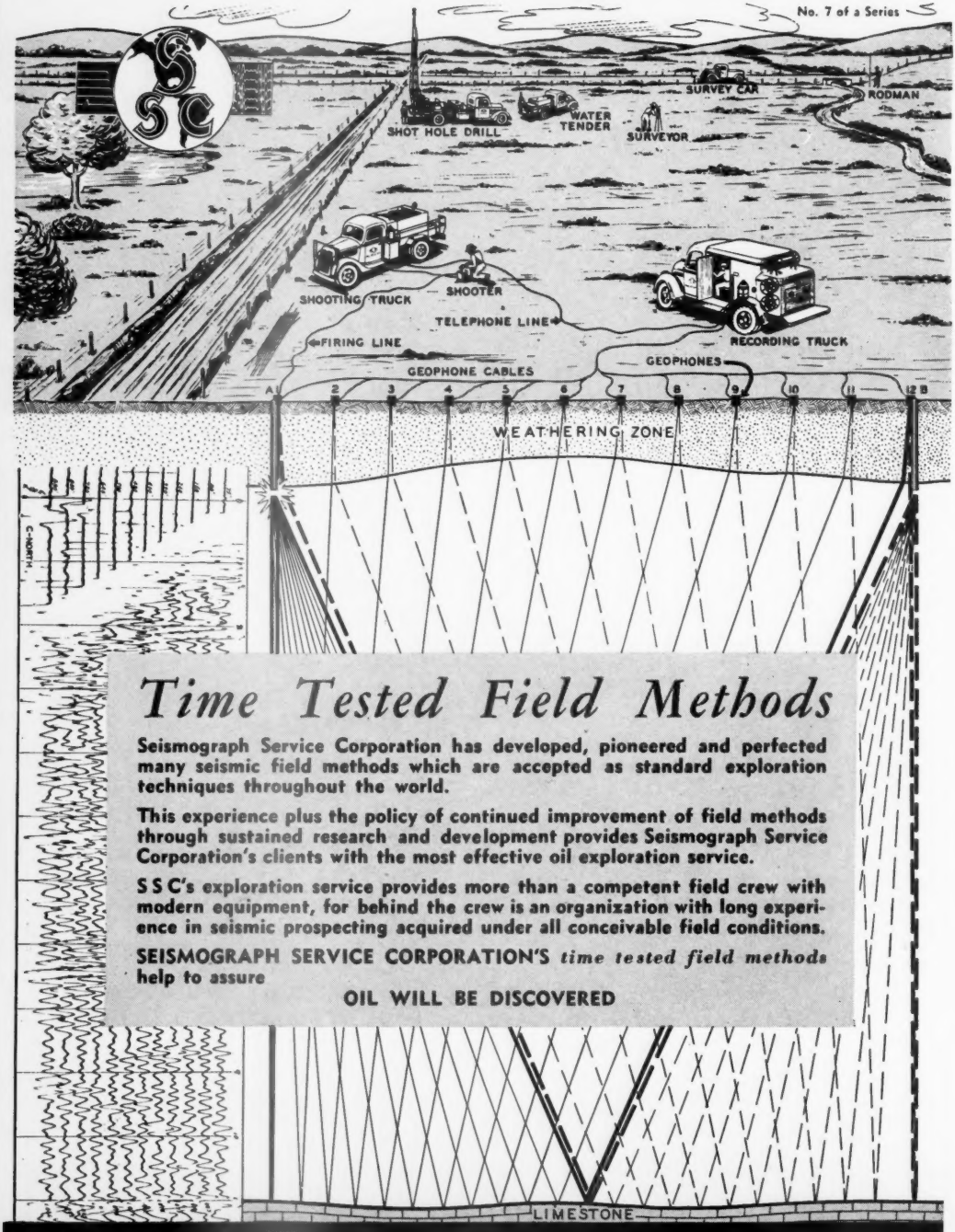

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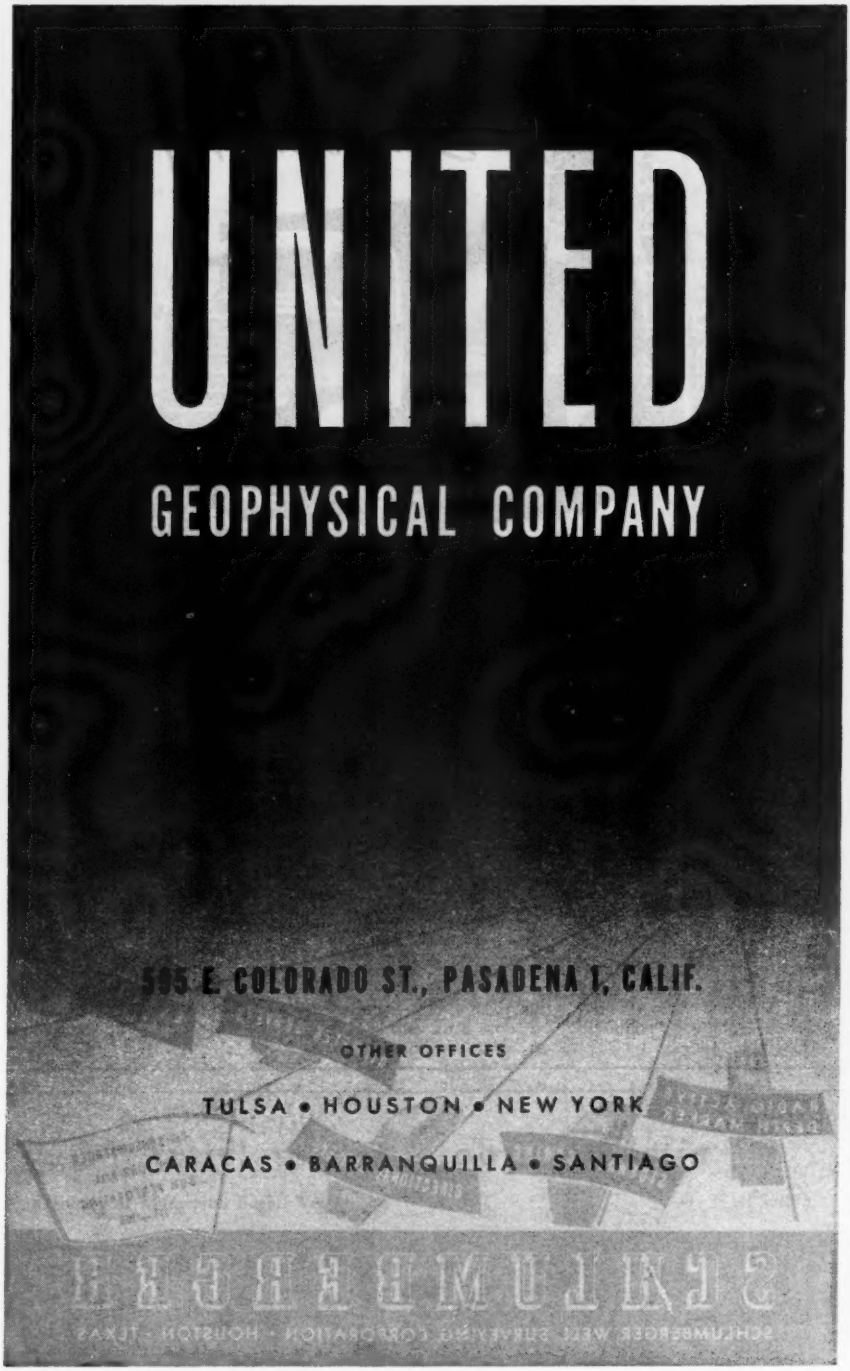
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El primer servicio que se ofrecerá a Venezuela será el de la acidificación de pozos petrolíferos. Las pruebas verificadas indican que, por medio del empleo de ácidos, se obtienen resultados eficaces en la mejora de las características de producción de los pozos petrolíferos venezolanos. En años anteriores, se ensayó este procedimiento en Venezuela, pero la dificultad de importar el ácido en grandes cantidades, y la falta de apropiado equipo de tratamiento y de un conocimiento exacto de la aplicación de las sustancias químicas a los pozos, impidieron un uso de mayores amplitudes. Hoy, aquellas dificultades han quedado vencidas. Se están enviando las necesarias cantidades de ácido a Venezuela, y tanto el equipo más moderno como la más experta ingeniería se hallan al alcance de la industria.

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Volume 30 Number 9

BULLETIN
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SEPTEMBER, 1946

RECENT INVESTIGATIONS BY UNITED STATES GEOLOGICAL SURVEY OF PETROLEUM POSSIBILITIES IN ALASKA[1]

JOHN C. REED[2]
Washington, D. C.

ABSTRACT

Because of the acute national situation in regard to oil during the war, the Geological Survey initiated detailed examinations in the summer season of 1944 in a number of the areas that, on the basis of considerable reconnaissance work over nearly half a century, were considered most likely to contain petroleum. In 1944 these studies were undertaken in five widely separated localities and similar investigations were continued in 1945. From them and the earlier more general examinations, three large areas are indicated as of most immediate significance. These may be designated as the Gulf of Alaska area, the Alaska Peninsula-Cook Inlet area, and northern Alaska. In each of these regions are a number of structures or other indications regarded as favorable for the possible accumulation of petroleum and that therefore seem worthy of intensive investigation.

In the Gulf of Alaska area the oil possibilities are confined to rocks of Tertiary age. Farther west in the Alaska Peninsula-Cook Inlet region, Jurassic rocks overlie a Triassic limestone that is presumed to be a possible oil source. In northern Alaska, the Navy Department is exploring the oil possibilities of Naval Petroleum Reserve No. 4 that lies in an extensive tract underlain for the most part by gently folded Cretaceous rocks. The Geological Survey is playing a part in the exploration program of the Navy Department.

Much additional information must be gathered before it is possible to estimate in quantitative terms the potential petroleum resources of Alaska. The determination of the value of these latent resources presents a challenge and the prospective returns well warrant tackling the job of determining the pertinent facts.

The principal purposes of this paper are to present a brief summary of the geology of several Alaskan areas of possible importance as sources of oil, to touch on the place of Alaska in the Pacific petroleum picture, and to point out in a general way the chances of Alaska contributing significantly to Alaskan and to wider Pacific markets in the light of recent investigations carried on in the Territory by the Geological Survey.

Alaska is a large Territory, one-fifth as large as the United States (Fig. 1). Around the northern rim of the Pacific Ocean from the tip of southeastern Alaska to the farthest of the Aleutian Islands is approximately 2,500 miles, and from

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[2] United States Geological Survey.

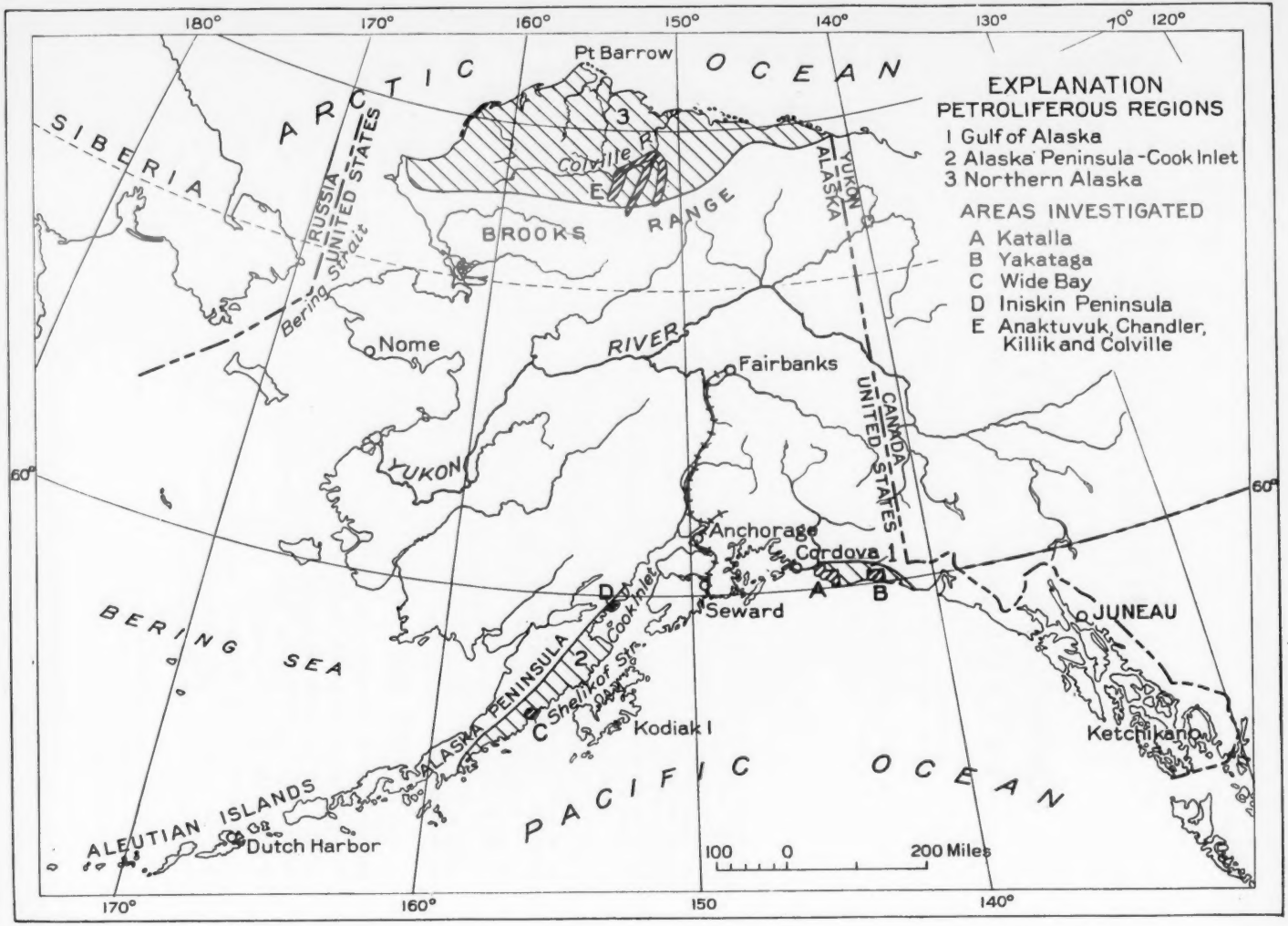

FIG. 1.—Index map of Alaska showing principal known petroliferous regions and areas recently investigated by the Geological Survey.

the coast at Seward at the southern end of the Alaska Railroad to Point Barrow on the Arctic coast is more than 800 miles. It follows, of course, that Alaska embraces a wide range of climate, terrane, vegetation, and other geographic features. Alaska is situated close to some of the great-circle steamer lanes linking North America and Asia, and the Territory occupies a unique position in relation to actual and projected intercontinental flight lines; witness, for example, the delivery of thousands of lend-lease planes to Soviet Russia by way of Fairbanks and Nome.

Exclusive of military and naval requirements, Alaska's present needs for petroleum products are relatively small, though of great local importance. Transportation in the Territory is in general difficult and expensive. The prewar population was only about 75,000 people about half of whom were natives. The population centers are widely scattered and, with the exception of Fairbanks, are largely at or near the Pacific coast. Several of the larger settlements are in southeastern Alaska. Considerable development of Alaska has been predicted in this postwar period and local markets for petroleum products will, of course, expand to the extent that development actually takes place. But, the world needs petroleum and Alaska needs new industries—what are the possibilities that one of these new industries may be the production of oil?

So far, virtually all the oil used in Alaska has come from outside sources. The only local source has been a small field near the southern coast which in the course of 30 years has yielded approximately 150,000 barrels of oil. This field has not produced since 1933, when a small refinery there burned down.

Because of the acute national situation in regard to oil during the war, the Geological Survey initiated detailed examinations in the summer season of 1944 in a number of the areas that, on the basis of considerable reconnaissance work over nearly half a century, were considered most likely to contain petroleum. In 1944 these studies were undertaken in five widely separated localities and similar investigations were continued in 1945. From them and the earlier more general examinations, three large regions are indicated as of most immediate significance (Fig. 1). These may be designated as the Gulf of Alaska region, the Alaska Peninsula-Cook Inlet region, and northern Alaska. In each of these regions are a number of structures or other indications regarded as favorable for the possible accumulation of petroleum and that therefore seem worthy of intensive investigation. The work done in 1944 and 1945 in each of these areas is briefly described.

FIG. 1.—Index map of Alaska showing principal known petroliferous regions and areas recently investigated by the Geological Survey

GULF OF ALASKA AREA

Geological Survey parties made detailed investigations in the Katalla and Yakataga districts in 1944 and continued the investigation in the Katalla district in 1945. Both districts are in a large area of Tertiary rocks stretching from near the mouth of the Copper River eastward along the coast to and beyond Lituya Bay.

Katalla district.—The Katalla district includes several groups of hills that are

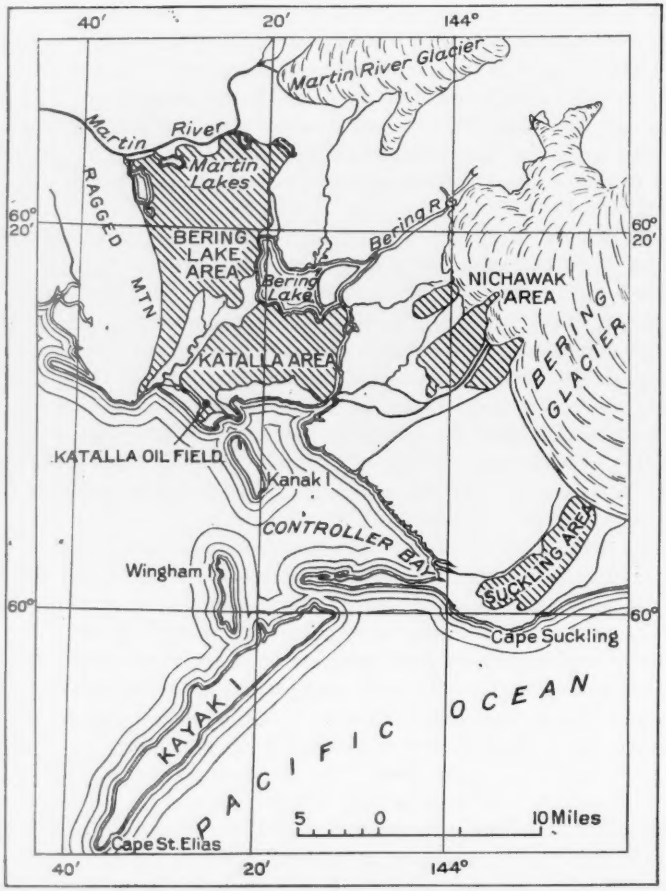

FIG. 2.—Sketch map of Katalla district, Alaska.

separated from each other and from the mountains to the north by glaciers, low marshlands, and water (Fig. 2). Oil seeps were discovered near the head of Katalla Slough in 1896, and drilling was begun in 1901. The Katalla oil field, which is on a low divide near the discovery seeps (Fig. 3) includes 18 productive wells ranging in depth from 366 to 1,810 feet. The field produced about 154,000 barrels of high-gravity paraffine-base oil in the period from 1902 to 1933.

In the area adjacent to the oil field (Katalla area), that was studied in 1944, the Katalla formation of Tertiary age is the principal rock unit exposed. It con-

FIG. 3.—View of part of Katalla area, showing location of Katalla oil field.
(Photo by Bradford Washburn)

FIG. 4.—View westward along coast in Yakataga district showing northward-dipping Yakataga formation (banded). Poul Creek shale in lower slopes and covered area. (Photo by Bradford Washburn)

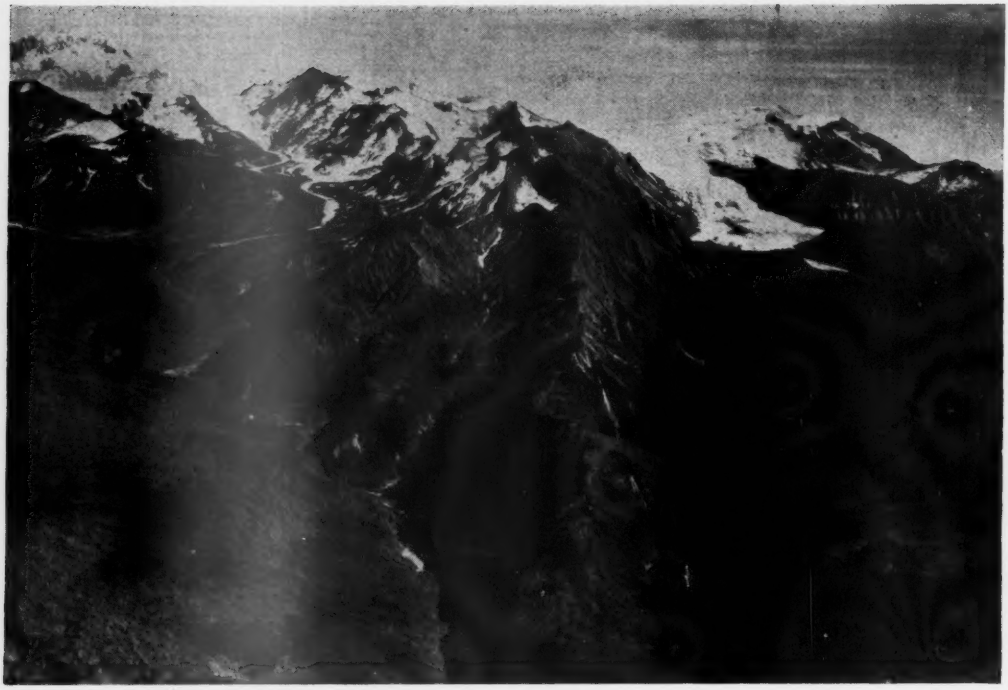

FIG. 5.—View eastward in heart of Yakataga district along axis of Yakataga anticline. Note broad synclines north and south of anticline. (Photo by Bradford Washburn)

FIG. 6.—View eastward near Cape Yakataga showing location of Sullivan anticline. (Photo by Bradford Washburn)

FIG. 8.—View southward showing part of Iniskin Peninsula.
(Photo by Army Air Forces)

FIG. 9.—View of Iba well No. 1, Iniskin Peninsula.
(Photo by Helmuth Wedow, U. S. Geol. Survey)

FIG. 10.—View southward in vicinity of Kukpowruk River toward western end of Brooks Range showing geologic structures etched out by erosion. (Photo by Army Air Forces)

FIG. 11.—View northward across Arctic coastal plain to Arctic Ocean about 100 miles southeast of Point Barrow. (Photo by Army Air Forces)

sists of more than 8,600 feet of marine shale, sandstone, and conglomerate. In a preliminary report[3] on the recent studies, 7 members of the Katalla formation are described. One of these is an organic shale member. The formation is intruded by small dikes, sills, and plugs and is overlain by unconsolidated Quaternary sediments.

The Tertiary rocks in the Katalla area are complexly folded and faulted. The structure is essentially a broad, southward-plunging syncline complicated by many northward-trending and some eastward-trending folds and by northward- and eastward-trending faults. Many of the folds are tightly compressed and some are overturned.

According to the preliminary report, the oil in the Katalla field probably was formed from organic material in the organic shale member and accumulated in fractures in or not far above the organic shale member. A fault north of the oil field may have hindered migration of the oil up the dip of the reservoir rocks. Most of the oil seeps in the Katalla area are on or near outcrops of the organic shale. Two oil seeps on Bering River and numerous gas seeps on Bering River and Bering Lake may indicate a petroleum source bed in or stratigraphically below the unnamed shale member.

In 1945 the investigation was extended to other parts of the Katalla district. The following information is from a report now in preparation by D. J. Miller on the results of this investigation. In the Martin Lakes-Bering Lake area is exposed a thick sequence of lower Tertiary marine shale, siltstone and sandstone that is believed to be in part equivalent to the lower part of the Katalla formation, and in part older. The lower and middle parts of the Katalla formation are exposed in the Nichawak area. Oil seeps in the Nichawak area apparently have their source in the organic shale member and in the underlaying shaly members. Rocks in part older than the Katalla formation, in part equivalent to that formation, and in part younger are exposed in the Suckling area and on Kayak and Wingham Islands. The structure in all of these areas is similar in intensity of folding and faulting to the structure in the Katalla area.

The recent work indicates that the geologic structures in the Katalla district probably are not favorable for large accumulations of oil, though accumulations comparable to the Katalla field may be associated with the organic shale, and possibly with lower beds, at other places in the district. Future exploration for oil in the Katalla district should be guided by at least one drill test in the oil field to determine more satisfactorily the source of the oil and the reason for its accumulation there and by drill holes on the more favorable structures on the south shore of Bering Lake and in the Nichawak area to test the organic shale member and lower beds.

Yakataga district.—The Yakataga district is a strip of mountainous country

[3] D. J. Miller, D. L. Rossman, and C. A. Hickcox, "Preliminary Report on Petroleum Possibilities in the Katalla Area, Alaska," 18 pp. Mimeographed. Accompanies geologic and topographic map and sections of the Katella area, Alaska. *U. S. Geol. Survey War Minerals Investigations* (1945).

on the south coast of Alaska about 125 miles east of Cordova (Fig. 1). The area is virtually uninhabited except for the few persons stationed at an airfield on the beach near Cape Yakataga and a few old time residents at the Cape. Practically all transportation to the district is now by air.

The following information is abstracted from a report as yet unpublished, by Edmund M. Spieker, Matt S. Walton, and Charles E. Kirschner, geologists of the Survey party that investigated part of the district in the summer of 1944.

The rocks of the district are all sedimentary and are divisible into an older group consisting of two sequences predominantly of sandstone and probably of early Tertiary age and a younger pair of units, the Poul Creek shale and the Yakataga formation of upper Oligocene age. The rocks of the older group range from 7,500 to 10,500 feet thick. The Poul Creek shale is dominantly dark with notable beds of sandstone, some conglomerate, and a few beds of limestone. Its thickness is 3,000 to 4,000 feet. The Yakataga formation (Fig. 4) is made up of a great variety of sediments including sandstone, conglomerate, shale, a little limestone, mudstone, siltstone, and claystone. It is at least 6,000 and probably nearer 8,000 feet thick.

The structure is fairly complex, comprising a succession of strongly compressed folds cut by faults that range widely in character and magnitude. The structural trend is easterly but individual axes curve in broad arcs. The Yakataga overthrust fault separates two structural belts. In the southern belt, four sharply folded anticlines are separated by broader synclines (Fig. 5). The northern belt, occupied mainly by the sandstone sequences of the older group, comprises a succession of closely spaced but more open folds that are cut by several thrust faults. The structural pattern in some ways is comparable to that of the Jura Mountains. This series of folds as seen from down the valley of the Yakataga Glacier gives the impression of one large anticline formerly called the Leeper anticline.

Oil seeps on the creeks near the coast east of Cape Yakataga drew attention to the area near the turn of the century, but so far virtually nothing has been done toward oil development. One hole drilled by the General Petroleum Corporation in 1926–1927 encountered no oil but the hole seems to have been unfavorably located. The numerous seepages and the geologic picture indicate that drilling would be likely to encounter at least some oil, but whether a large oil field awaits development is less certain. The geologic conditions appear favorable enough to warrant exploratory drilling. The Yakataga anticline and an anticline sometimes called the Sullivan are believed to be particularly favorable structures, especially on their northern flanks, but the recent Survey party did not complete its studies of the latter anticline. The so-called Sullivan anticline is the one nearest the coast east of Cape Yakataga (Fig. 6).

ALASKA PENINSULA-COOK INLET REGION

In the Alaska Peninsula-Cook Inlet region indications of petroleum have been recognized at intervals throughout a tract that extends for more than 250

miles along the eastern flank of the Peninsula (Fig. 1). The local areas at which most active search for oil has been made in the past from northeast to southwest are the Iniskin-Chinitna area, Cold Bay, Jute Bay, Portage Bay, and Wide Bay. The bedrocks in all of these areas consist dominantly of Mesozoic sandstones and shales. The lowest sedimentary members of the sequence and presumably the source of such oil as may be found there is a Triassic limestone, but the greater part of the sequence that has been penetrated by drill tests is Jurassic. Only a few deep tests have been made at any of the known structures and, although showing

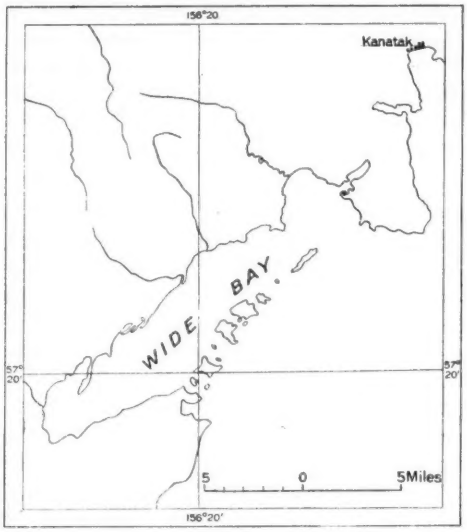

FIG. 7.—Sketch map of Wide Bay area, Alaska.

indications of oil, none of them disclosed commercial amounts. The following is a record of the deepest test holes in each of the following areas: Iniskin—8,800 feet; Jute Bay (Bear Creek structure)—7,500 feet; Portage Bay (Pearl Creek structure)—5,000 feet. None of the known structures has as yet been adequately tested. In most of them the single deep test mentioned is the only drilling that has been done.

In the summer of 1944 detailed investigations were made in two of the more hopeful areas in the Alaska Peninsula-Cook Inlet region. One of the parties operated principally in the vicinity of Wide Bay and the other on the Iniskin Peninsula. The investigation of the Wide Bay area was continued in 1945.

Wide Bay area.—The Wide Bay anticline at Wide Bay covers more than 300 square miles and is on an axis that extends for many miles northeasterly (Fig. 7).

About 60 square miles covering the southwest part of the anticline were mapped in the 1944 season. The field work was continued in the summer of 1945 and the rest of the anticline was mapped. The following information is abstracted from selections from a preliminary report[4] on the 1944 work. Four faunal zones and eight subzones were identified in the previously recognized Kialagvik formation of Middle Jurassic and the Shelikof formation of Upper Jurassic age. Although individual beds are lenticular and any one lithologic unit can not be traced very far, the presence of these faunal zones permits the recognition of the variations in lithologic character both vertically and horizontally. These observations brought out certain structural features not otherwise evident.

The axial part of the anticline is largely concealed beneath Wide Bay. Dips ranging from 12° to 20° were observed on the southeast flank and 4° to 17° on the northwest flank. The anticline is complicated by a series of transverse faults, mostly of small displacement.

The Wide Bay anticline is the most favorable structure now known on the Alaska Peninsula for a test of the Triassic rocks and the lower part of the Jurassic rocks. It is the only well defined fold where the Kialagvik formation is exposed. A drill hole on the north shore of Wide Bay would begin about 2,000 feet below the top of the Kialagvik, much lower than the start of any of the holes drilled on other structures on the Alaska Peninsula. Oil seepages have been observed from the Kialagvik on Wide Bay but were not seen during the recent investigations. The objective of any well drilled on the Wide Bay anticline should be to penetrate the Triassic rocks.

Iniskin Peninsula.—On the Iniskin Peninsula (Fig. 8) the work in 1944 was concentrated in the Fitz Creek area, the location of the principal known structure. This area includes the Iba well, which was bottomed at a depth of 8,775 feet in September, 1939. The Tuxedni sandstone of Middle Jurassic age is the only formation exposed on the Fitz Creek structure. The lower part of the Tuxedni formation is probably equivalent to part of the Kialagvik formation on the Alaska Peninsula.

Although the report on the Iniskin area is not yet available, it is evident that the detailed work will result in the recognition of faunal zones and subzones in the Tuxedni sandstone. These faunal units indicate that the structure of the Fitz Creek area is considerably more complex than formerly was thought. For example, in the vicinity of the Iba well the beds exposed on one side of the structure are separated by a longitudinal fault from those on the other side and the displacement may be 1,000 feet or more. The structure is also complicated by transverse faults.

[4] L. B. Kellum, S. N. Daviess, and C. M. Swinney, "Geology and Oil Possibilities of the Southwestern Part of the Wide Bay Anticline, Alaska," 17 pp., illus. Mimeographed. Accompanies geologic map of the southwestern part of the Wide Bay anticline, Alaska. *U. S. Geol. Survey War Minerals Investigations* (1945).

The earliest drilling operations on the Iniskin Peninsula were in the vicinity of Oil Bay, where 4 wells were drilled in the period 1898–1906 by the Alaska Petroleum Company. The first well was drilled to more than 1,000 feet and was reported to have found some oil at from 500 to 700 feet. Gas was encountered at various depths. The well was abandoned in 1903 after drilling into a strong flow of salt water. The other 3 wells were all abandoned at depths of less than 1,000 feet. These wells were drilled on seepage locations with no apparent regard for structure. They started in the Tuxedni sandstone and probably drilled into porous beds from which the seepages were issuing.

The Alaska Oil Company carried on drilling operations at Dry Bay in 1902 to 1903 and drilled two shallow wells, the deepest 320 feet.

The only deep test in the district was the drilling by the Iniskin Drilling Company of the Iba well No. 1 in 1936–1939 (Fig. 9). This well, 8,775 feet deep, has yielded a few barrels of oil. The oil has a gravity of 46.8 and is a paraffine-base crude yielding 59 per cent of gasoline and having a low sulphur content.

NORTHERN ALASKA

The northern foothills and the Arctic lowland of northern Alaska make up a broad stretch of country lying between the Brooks Range on the south and the Arctic Ocean on the north. This province is underlain almost entirely by Cretaceous rocks but Triassic rocks are present in the southern part near the Paleozoic rocks of the Brooks Range. North of the Triassic rocks, which are marine and are intensely folded, is a belt of Lower Cretaceous rocks (see Fig. 10) also largely of marine origin which are overlain in turn by a thick sequence of Upper Cretaceous rocks that is in part of marine and in part of terrigenous origin. Terrigenous rocks, with coal, are well exposed along the Colville River below the mouth of the Anaktuvuk River. The rocks are progressively less intensely deformed northward from the Brooks Range toward the Arctic Coast. A wide belt adjacent to the coast is covered by a mantle of frozen, but otherwise unconsolidated, younger materials so that the underlying bedrocks are not available to direct observation. Lakes are very abundant in this Arctic lowland belt (Fig. 11).

The province just briefly described includes a tract of about 70,000 square miles of which 35,000 is in Naval Petroleum Reserve No. 4. The province is known to contain a number of oil seepages, the largest and best known of which are on Cape Simpson about 50 miles east of Point Barrow.

Since the spring of 1944 the Navy Department has carried on exploration work in Naval Petroleum Reserve No. 4 aimed to determine whether or not the Reserve contains commercial quantities of oil. This exploration work is expected to continue at least for several years, although from now on it is anticipated that most of the work will be done on a contractual basis rather than directly by the Navy Department. The exploratory work has proceeded satisfactorily thus far and a large number of data have already been accumulated. A test hole located

on an attractive anticline in the southeastern part of the reserve was drilled in the summer of 1945 to a depth of nearly 2,000 feet (Fig. 12). Drilling was suspended in September for the winter season.

In the summer of 1944, the Geological Survey operated a small field party along the southeastern edge of the Reserve along the Colville River and obtained stratigraphic information as well as structural data in addition to those collected by Survey exploratory parties a generation and more ago. Subsequently the

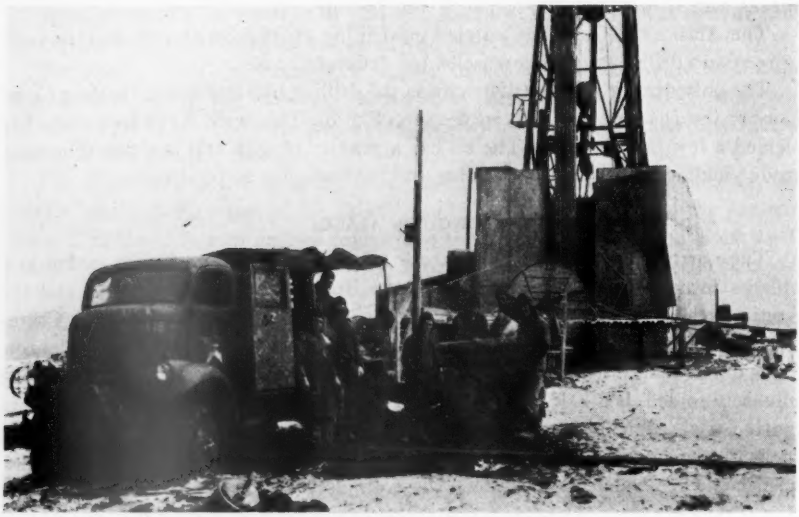

FIG. 12.—View showing drill rig on location in southeastern part of Naval Petroleum Reserve No. 4. (Photo by Stewart H. Folk)

Survey has carried on some of the geological investigations in connection with the Navy Department's program. It was early recognized that light would be shed on the structural and stratigraphic conditions in the eastern part of the Reserve by extrapolation from areas south of that part of the Reserve where the rocks are better exposed and the structures more distinct. Three Survey parties, two supported entirely by Navy funds, were flown north of the Brooks Range before the breakup in the spring of 1945 and proceeded down the Anaktuvuk, the Chandler, and the Killik and Colville rivers, respectively, making detailed stratigraphic and structural studies as they went. A laboratory was set up by the Geological Survey in Fairbanks and is equipped for carrying out many of the processes that are required in an exploration program of the kind underway. The laboratory processed samples and specimens collected by the field parties as well as core samples from the drilling at Umiat in the extreme southeastern part of the

Reserve and material from shallow drilling by the Navy near Cape Simpson in the vicinity of the large seepages. The field and laboratory work have yielded a relatively satisfactory picture of the stratigraphy of the rocks underlying the part of the Reserve now being explored most intensively. The Survey's part in the program was expanded in the winter of 1945–1946.

CONCLUSIONS

It is evident that much additional information must be gathered before it is possible for geologists to estimate in quantitative terms the potential petroleum resources of Alaska. From what is now known it seems evident that the attempt to develop an oil industry at some of the prospective fields in the Territory is likely to be attended by success. The attempt to bring in such an oil field, however, is expensive and attended by considerable risk even under the best circumstances. In a remote difficult region like Alaska the hazards are especially great but if those conditions are realized and provided for, it seems that the determination of the value of the latent petroleum resources of the Territory presents an interesting challenge and the prospective returns well warrant tackling the job of determining the pertinent facts.

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VOL. 30, NO. 9 (SEPTEMBER, 1946), PP. 1444-1516. 17 FIGS.

GEOLOGICAL OCCURRENCE OF OIL IN UNITED KINGDOM WITH REFERENCE TO PRESENT EXPLORATORY[1] OPERATIONS

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ABSTRACT

The United Kingdom has been actively prospected for oil since 1936 by several major companies, but during the war no details have been released although oil has been commercially produced during this period. The question of oil occurrence in the United Kingdom is discussed in detail on the basis of fundamental geology, and it is shown from geological history that since Devonian time this country has lain far outside the zones of geosynclinal sedimentation and instead has formed part of the eastern edge of the postulated Atlantean Continent, whereby it has either been a land area for much of succeeding geological time or else has been covered by shallow shelfseas with relatively thin sedimentation. Locally, suitable environments for oil generation may have occurred in the Carboniferous and Jurassic. The United Kingdom has been the meeting place of three major orogenic movements in which violent folding has taken place followed by lengthy erosion periods. The geological pattern of the United Kingdom is characterized by a number of rigid Lower Paleozoic massifs, either exposed or only shallowly buried, with intervening downwarps containing locally thick Upper Paleozoic and Mesozoic sediments. Oil indications occur over much of the stratigraphical column, particularly in Carboniferous and Jurassic rocks, and are commonly found in close and apparently genetic association with non-marine sediments. Suitable stratigraphical and structural conditions for oil pooling occur in southern England and east-central England but widespread testing has proved commercial production only from the English equivalent of the lower Pottsville, Pennsylvanian system, in the latter region.

It is concluded that the oil prospects of the United Kingdom are definitely restricted both stratigraphically and areally by reason of the geological factors which have together contributed to its development. More pools may be found but nothing of large dimensions is expected.

INTRODUCTION

An intensive search for oil has been taking place in Great Britain during the past 9 years, in the course of which several hundred wells have been drilled and oil has been discovered and produced on a small, yet commercial scale. As the details of the progress of this search have naturally not been made public since 1939 for security reasons, few facts concerning this exploratory effort are known to anyone outside the companies who are directly contributing to it.

It will doubtless be remembered by the older members of the Association that toward the end of the last war a similar, but much more restricted, search took place under American supervision and it is thought that the geological aspects of the present campaign, in which two major American oil companies have taken part, would be of some interest, particularly in view of the stratigraphical range of the prospects which have been deemed worthy of investigation and subsequent testing. This paper is therefore intended to discuss the geological reasons which have moulded the pattern of the second British oil search. The approach to this subject is along the lines of geological speculation applied to the known structural and stratigraphical geology of the United Kingdom such as might be follow-

[1] Published by kind permission of Anglo-American Oil Company and Standard Oil Company (New Jersey). Manuscript received, February 26, 1946.

[2] Chief geologist, Anglo-American Oil Company.

FIG. 1.—Map of United Kingdom showing county boundaries.
(1 inch equals 75 miles)

ed by an impartial investigator desiring to assess the chances of oil production therein. It is not intended to describe in detail the geological information obtained from the actual exploratory operations as these are rather of local interest only, and for those interested in this aspect the D'Arcy Exploration Company has lately made public in England a full geological description of the results of its extensive activities. An attempt is made instead, to deduce the oil prospects from a broad philosophical basis and later to compare these theoretical conclusions with those actually proved from drilling operations.

ACKNOWLEDGMENTS

The geological information in this paper is to a large extent derived from the work of the Geological Survey of Great Britain, whose published data in the form of memoirs, maps, and other publications have been freely utilized. This material has provided an excellent basis of surface geological information from which to build a picture of the oil possibilities of the country, and grateful acknowledgment is hereby made of this assistance. In addition, thanks must be paid to the individual officers of the Survey who have always been ready to discuss and advise on problems which have arisen during the course of exploration.

It is an interesting fact that although the surface of the country has been mapped with considerable accuracy yet knowledge of the subsurface is scanty and restricted on account of the relative lack of deep wells and borings. Over large areas the subsurface geology is entirely unknown and can be predicted only in terms of speculation based on little reliable control. In the present search for oil all possible sources of subsurface information have been investigated, and it is pleasant to put on record that the mining industry, particularly the colliery companies, have co-operated to the fullest extent in providing their quota of information to the geological staffs of the companies engaged in this exploratory work. It is not possible to mention all these sources individually, particularly when it is made known that in the Yorkshire-Notts. coal field alone more than 70 different colliery companies provided subsurface information; but it is intended here to acknowledge collectively the assistance which has always been courteously extended.

The paleogeographical maps are based partly on those contained in L. Wills' textbook, *The Physiographical Evolution of Great Britain*, and L. Dudley Stamp's textbook, *An Introduction to Stratigraphy*; acknowledgment is made to these two authors for the information which has been derived from their works.

For details of the D'Arcy Exploration Company's results acknowledgment must be made to the Geological Society, in whose journal these have recently been published.

Finally, acknowledgment must be made of the work of the members of the geological staff of the Anglo-American Oil Company, subsidiary of the Standard Oil Company (New Jersey), who have taken part at various times in the company's exploratory work, and whose reports have been consulted during the preparation

of this paper. In particular, mention must be made of Douglas A. Greig with whom the writer has discussed with advantage the subject matter of this contribution on many occasions, while the reports of Peter H. N. White relating to the company's gravity surveys in this country have been of much assistance on the structural aspects of the problem. Thanks must also be paid to James M. Michie for his skilful and painstaking drafting of the illustrations presented with this paper.

History of Oil Exploration in Great Britain

Before proceeding to consider the geological reasons which have influenced the search for oil in this country, it is thought that a brief historical summary of British oil exploration would not be irrelevant. Organized scientific search for oil in Great Britain is of relatively recent date, and can be said to have started in 1918. Exploration has been restricted to two active periods separated by a lengthy interval of 14 years, 1921-1935, during which all drilling activity was virtually at a standstill. This may seem surprising in view of the fact that this period saw a world-wide expansion of exploratory activities and outstanding advances in the technique of prospecting for, and producing, crude oil, but many factors contributed to this state of inactivity, chief of which no doubt were the political and legal aspects of the matter.

Prior to the passing of the Petroleum (Production) Act of 1934, the question of the ownership of any possible oil accumulations in this country had never been legally defined, and this factor, in conjunction with lack of experience regarding the likely scale of compensation and royalty payments, was sufficient to deter any would-be prospectors from operating under such uncertain conditions whereby there could be no predictable prospect of financial success even though commercial oil pools were to be found. Politics played a considerable part in this matter, particularly as regards the question of royalty payments, in view of the ever growing demands by the Labour Party for the nationalization of the country's resources, and the cessation of royalty payments on coal to the owners of the mineral rights. It required the stimulus of war to bring this matter to a head, and the demand for petroleum products near the end of the first World War in 1918 led to the first scientific search for oil in the country. A Government bill proposing to pay a small royalty to the owners of oil lands was defeated on this point and eventually a compromise was reached whereby Government license was required to drill for oil, with the question of ownership and royalty to be held in abeyance until after the war.

Under powers acquired by the Defence of the Realm Act of October, 1918, the Government itself took over certain sites for test drilling, retaining under contract S. Pearson & Son, Ltd., for this work, and operations were commenced when actually the time of vital need had passed. Eleven wells were drilled, comprising 9 tests of the Lower Carboniferous in the Midlands, and two of the same formation in Scotland. These wells were scientifically located after careful surface geological

work, but only one small producer resulted, the celebrated Hardstoft well in Derbyshire.

With the artificial stimulus of war removed, the still unclarified legal position and poor results of the first exploratory campaign led to a cessation of further work apart from the drilling of two dry holes close to the Hardstoft well in 1925.

Some operators were of the opinion, however, that the oil prospects of the country had been very inadequately tested by the few wells drilled, and that the surface indications, considered in conjunction with the local geology, were such as to merit further investigation should the legal ownership of oil deposits be placed on a favorable and clear basis. Other eminent authorities, on the other hand, have steadfastly refused to believe in the occurrence of oil accumulations on a commercial scale in this country, apart from small and sporadic pools which would be in the nature of geological freaks, preserved from dispersal by lucky chance.

In 1934, the Petroleum (Production) Act was passed which vested the ownership of all petroleum hydrocarbon deposits in the Crown, and empowered the Board of Trade to grant licenses giving exclusive rights to prospect and drill for oil over areas selected by bona-fide operators with adequate financial resources. These prospecting licenses have a three-year life, with the option of two additional yearly extensions; they cover a maximum area of 200 square miles and at present a yearly rental of 5/-d. ($1.00), or, in some cases, 10/-d. per square mile, is paid by the licensee for the initial three years with an increase in rental should the option of the yearly extension be exercised. The licensee pays a royalty to the British Treasury of 4/-d. per ton of oil produced.

For the exploitation of reserves proved under prospecting license, the operator can take out a mining license with a life of 50 years and involving higher rentals which can, however, be credited against royalty payments.

Working obligations are attached to all licenses whereby geological and/or geophysical work has to be carried out, followed by test drilling on a high proportion of the licenses issued to any operator. Where geological work, however, reveals the absence of any prospects which warrant test drilling, the obligation to drill, for that particular license, may be transferred to another licensed area, or the licensee may relinquish this license without further obligation.

These liberal conditions, which stabilized on a firm basis and encouraged the whole question of oil exploration in this country, led to an immediate response by interested companies and from 1936 onward a continuous program of exploration has been carried out all over Great Britain by various companies using the latest techniques. The result has been, on the whole, disappointing, and so far has tended to confirm the opinions of the original pessimists. Oil has been produced in small commercial quantities, mainly by the D'Arcy Exploration Company, subsidiary of the Anglo-Iranian Oil Company Limited, and also by the Anglo-American Oil Company, associate of the Standard Oil Company (New Jersey); further attractive prospects still remain to be tested, however, with the possibility of

proving additional reserves, but already large areas of the country can be eliminated as a result of the work done to date.

The history of oil prospectiong in this country is therefore seen to have followed a different course from that of similar operations in most other countries, and it is of some interest that the nationalization of the country's oil resources should have been carried out without much public comment or interest, possibly because of a general lack of knowledge about the oil industry which still prevails among the majority of the population, and possibly also because the lack of success which rewarded the first drilling campaign in 1918-1920 may have appeared to many to discount the eventual establishment of a domestic oil industry in this country, and the matter therefore was not considered of high import.

Principal Oil Occurences

Surface, and subsurface, indications of solid and liquid hydrocarbons and gas are plentiful in England and to a less degree in Scotland. It is indeed surprising at first sight that with so much superficial evidence of oil the inauguration of a settled legal and political policy regarding the ownership of possible oil deposits should have been so long delayed. Traces of oil and bitumen have been recorded in the Paleozoic and Mesozoic rocks from the Ordovician onward, and oil shales are a common occurrence in certain parts of the stratigraphic column, although it is believed that the presence of oil shale is not necessarily an indication of the presence of liquid petroleum, and may indeed point to conditions of deposition which were inimical to the generation and preservation of this material.

Many of these oil occurrences are believed to be of local *in situ* derivation, and as such are of no commercial significance, occurring in accordance with the reasonable theory that hydrocarbon formation in sediments is not a unique occurrence but probably takes place to some extent, however limited, in most sedimentary deposits of any thickness in which the remains of animal or vegetable life are entombed. Such oil indications are therefore of no interest when considering the prospects for large-scale commercial accumulations, which imply the unique conjunction of favorable source material, depositional environment, conditions for hydrocarbon conversion, *et cetera*, followed possibly by extensive migration from the original source. In the following notes, therefore, only the larger and more extensive oil indications which might have some bearing on the presence of such accumulations are discussed, and these may be classified on a geological-geographical basis as follows.

Carboniferous limestone in central England and Scotland

The Carboniferous limestone is a massive limestone facies of the Lower Carboniferous which occurs extensively in the Midlands of England. In Derbyshire it occurs at the surface over an extensive area in the form of a large flat-topped dome, and many indications of hydrocarbon material, both solid and liquid, have been recorded on the eastern flank and northern plunge of this major struc-

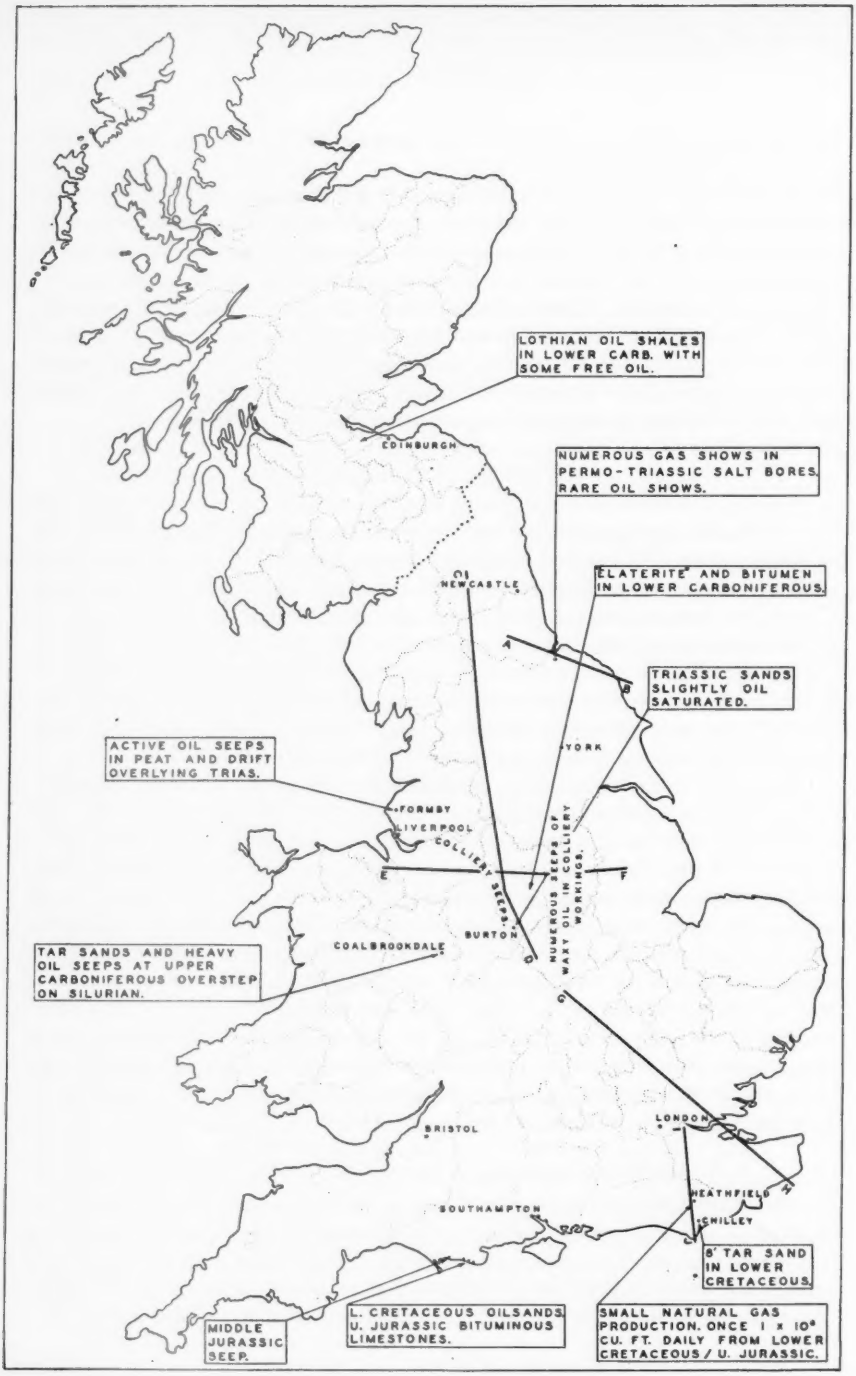


FIG. 2.—Map showing principal indications of oil and gas, and location of section lines. (1 inch equals 75 miles)

tural feature. One of the best known occurrences is the exudation of a yellow viscous liquid turning on exposure into a species of yellow elaterite, which is found in many localities associated with faulting. Liquid oil has been recorded from many localities in wells and it is of considerable interest to note that almost all of these recorded oil showings lie near the unconformable overlap of the succeeding marine shales of the Millstone grit, which are themselves bituminous at outcrop. This suggests that the limestone showings may be in part derived from the overlying shales by downward migration, though on the other hand, showings of oil have been reported at considerable depth within the limestone, though not on a large scale.

In South Wales the outcrop of the Carboniferous limestone contains some traces of a volatile oil, and also of a waxy material. These possibly may be only examples of the ubiquitous formation of hydrocarbons in small quantities in most marine sediments, and it is difficult to judge the exact significance of such shows.

In Scotland there is a remarkable development of rich oil shales in a very restricted area in beds equivalent in age to the upper part of the Carboniferous limestone of England, though these beds are of near-shore, partially fresh-water type. Within the shale field the extensive mine workings have in many places revealed the presence of crude oil in some quantity, and the question of the source of this oil has long been the subject of much discussion. Unfortunately, the picture is complicated by the presence of igneous intrusions in the oil-shale section and the opinion is widely held that the fluid oil is the result of distillation of these bituminous shales by the hot intrusive igneous material. This view may be correct but occurrences of oil are known which are not in close proximity to such intrusions, and are in sandstones immediately adjacent to oil-shale seams. On the other hand, there is clear field evidence that some oils must have been derived from the subsurface distillation of oil shales in view of the fact that masses of intrusive rock which are soaked in oil have been observed. Analysis of these various oils suggest a common origin, and it is of interest that their iodine numbers (indicative of the proportion of unsaturated hydrocarbons) are alike, and markedly lower than the corresponding value for crude oil artificially distilled from oil shale which ordinarily has a high unsaturated content. Hence, even if the free oil is the result of underground distillation, the physical processes responsible for its production must have been very different from those of artificial distillation which presumably gives rise to the unsaturated content of shale oils by "cracking" at higher temperatures than those which are present in the intrusive rock. Samples of these free oils from the shale field have on occasion been submitted to the United States Bureau of Mines, and the opinion has been expressed that they would have been labelled as true petroleums if their source had not been known.

Official opinion inclines, therefore, to a distillation source for this oil, with migration accounting for those occurrences which are remote from igneous intrusions. This is not entirely satisfactory, however, and does not explain the occurrence of oil shales in almost direct contact with intrusives which are apparently

unaffected; while the question of the small oil accumulation at Midlothian just outside the shale area is likewise not explained, particularly as the section in this area shows little, or no, oil shale, and no intrusions are present until much lower in the section.

MIDDLE COAL MEASURES THROUGHOUT ENGLAND

Crude petroleum has been obtained, in some places in quantity, from the Middle Coal Measures in nearly every coal field in England, with the exception of those in Northumberland and Durham. This type of oil is remarkably similar, both physically and chemically, and though it occurs in liquid form in coal workings it is generally solid at the surface in the form of a greenish brown wax or grease. Chemical analysis shows a large proportion of the higher members of the paraffine series up, to and including pure pentacontane ($C_{50}H_{102}$). A typical analysis of such a crude is as follows.

Specific gravity at 60°F./60°F.	0.8435 (36.3° A.P.I.)
Pour point	55°F.
Sulphur content	0.12%
Water content	0.10%

Preliminary Distillation I. P. 24/42

Initial boiling point	Approx. 110°C.
120°C.	2%
125°C.	2.5%
130°C.	5.5%
175°C.	8.0%
200°C.	10.0%
225°C.	12.5%
250°C.	15.5%
275°C.	19.5%
300°C.	25%

These colliery occurrences always seem to be associated with faulting either in the roof or the floor of mine workings, and do not occur normally as impregnations of the sandstone beds which often occur in considerable thickness in the Coal Measures. Ordinarily the quantity of oil is small and its occurrence does not have a long life, but several outstanding cases are known in which the underground seeps have yielded oil for years, for example, Riddings Colliery, Derbyshire, where 7 barrels per day were collected for 2 years, and Manvers Main Colliery, Yorkshire, where oil was collected for 14 years, the initial production being 100 barrels per day for several days. From Clowne Colliery in Derbyshire a similar occurrence was reported, and a large volume of oil was collected for distillation in addition to a considerable quantity used in the colliery for greasing and lubrication. Additional cases of small quantities of this waxy crude in colliery workings are being continually recorded, and these oil seeps are of sufficiently widespread occurrence for it to be said with some accuracy that they are a typical product of Coal Measure sediments.

The genesis of this oil is obscure. Its presence does not appear to be associated with any structural disposition of the Coal Measures apart from minor faulting of these sediments, and in most places the larger faults are devoid of any such oil.

Its waxy nature, and the presence of high molecular-weight hydrocarbons, suggests a specialized source, and it has been considered that this oil might be associated in some way with the common occurrences of cannel coal in the Middle Coal Measures. These cannel coals are formed from the most strongly resistant vegetable matter such as spores, pollen exines, and cuticles, which are predominantly waxy and fatty in composition; hence, there appears to be a basic relation between this type of coal and the waxy Coal Measure oil on the grounds of chemical composition. There is good reason to believe, therefore, that these showings are indigenous to the Coal Measures and are formed *in situ* with little subsequent migration excepting that which may take place along fracture planes. The small volume, short-lived occurrence, and completely sporadic distribution of these oil occurrences render them of no attraction as a drilling objective, but they are of interest in that together they represent a considerable volume of liquid hydrocarbons which, if concentrated in one place, would be of commercial size and warrant exploitation.

UPPER COAL MEASURES IN SHROPSHIRE

Extensive and well known oil occurrences in the Coalbrookdale area of Shropshire range from oil seeps to solid bitumen and tar sands, and geologically they occur in the lower part of the Upper Coal Measures, where these overlap the remainder of the entire Carboniferous section and overstep onto the old Paleozoic rocks of central England. An interesting occurrence, probably related to these showings, has been noted southwest of Coalbrookdale where a scum of black oil has been known to occur since Roman time on a pool of water which lies over an inlier of pre-Cambrian rocks, while a bitumen-cemented breccia of pre-Cambrian rocks occurs nearby.

The origin of this oil is unknown and even now can not be explained. Its apparent association with an unconformable overlap gives rise to several possibilities ranging from *in situ* formation in the Upper Coal Measures, to upward migration from the old Paleozoic beds, or more likely long-range migration along the unconformity from the thick Carboniferous section farther north in Staffordshire. Inspection of these showings suggests they represent relics of a previous accumulation and their inspissated character even at depth renders them unattractive.

TRIAS IN CENTRAL ENGLAND

The occurrence of an oil-impregnated sandstone of Lower Triassic age has long been known at Burton-on-Trent in Derbyshire. Originally it was reported to occur over a distance of 1½ miles and to be 5 to 6 feet thick but present investigation can not confirm this extent of the sand. As seen now the occurrence is not impressive as the rock is very lightly impregnated, but analysis of typical samples has shown a content of more than 5 per cent by volume even after the lengthy period of erosion to which these beds have been exposed. The Trias at this point is thin and fractured while the underlying Carboniferous is known to be

rising steeply against the unconformity separating these two formations, so that this could be a case of vertical migration from underlying source rocks. Chemical analysis does not suggest a Carboniferous origin, however, by analogy with analyses of other crudes of this age, but the available information on crude-oil identification from chemical analysis is too meager to put too much reliance on such a finding. On the other hand, the Triassic sediments near Burton do not appear as at all likely source rocks. Although nothing but a "relic" now, it is possible that originally this impregnation may have represented a considerable volume of oil now dispersed.

TRIAS IN LANCASHIRE

Interesting and puzzling oil seepages are known in northwest Lancashire near the sea coast over an area of 10 square miles centering on the town of Formby.

These seeps occur in recent peat deposits which overlie a section of glacial débris, clays, and sands. the underlying solid rock being continental-type red sandstones of Triassic age. A deep test here by the D'Arcy Exploration Company has revealed the presence of 6,000 feet of Trias and Permian redbeds consisting almost entirely of sandstones, some of which are probably eolian in origin. The presence of these oil showings has been known locally for well over 100 years and the local inhabitants have used the oil-impregnated peat as fire-lighting material.

The largest seepage is observed on a drainage ditch cut in the low terrane of the Lancashire coastal plain. When dry, this peat is seen to be black and saturated with oil, while when wet, pools of oil float on the surface of the water. Oil is contained not only in two separate lyers of peat but also in cavities in an intervening silty clay formed by the decay of contained reed material. At a near-by locality free oil seeped into a shallow shaft dug in the peat to the extent of 7 gallons in 12 hours.

Analysis of the seepage oil by the Anglo-American Oil Company showed the following characteristics.

Specific gravity at 60°F	0.8885 (27.75° A.P.I.)
Viscosity Saybolt	
Universal at 100°F	178″
do. at 210°F	46.3″
Pour point	Fl @ 0°F.
Sulphur	0.25%
Iodine No. (Wijs)	13½
Saponification value	1.2 mgm. KOH/gm.
Acidity	0.35 mgm. KOH/gm.
Specific gravity key fraction No. 1 (U. S. Bureau of Mines)	0.835=38° A.P.I.
Distillation—Initial boiling point	205°C.
225°C.	1½%
250°C.	7%
275°C.	15%
300°C.	23½%
325°C.	33½%
350°C.	52%*

The opinion was expressed by the analyst that two types of oil were present, one

* Cracking occurs—distillation stopped.

of vegetable origin, and the other similar to the crude oil of the industry. It is of interest that the Formby crude fluoresces with a yellowish brown color in ultraviolet light which is entirely different from the fluorescent color of any other Carboniferous crude in the country, and this may be an indication of an origin in some formation other than the Carboniferous, or else of a different type of source material within the Carboniferous.

The question of the origin of this oil is still unsolved. The restriction of the seepages to the Pleistocene peat area originally gave rise to consideration of a possible source in this material though geologically such an occurrence is most unlikely. Our knowledge, however, of the conditions of oil formation is still so elementary that any possiblility, however remote, merits investigation until an indubitable set of geological criteria has been established for the oil-forming process; and the evidence of the analysis that vegetable-type oil was present lent further encouragement to review the peat possibilities.

A biological examination of the peat beds showed it to be a normal sedge peat containing considerable quantities of algae of which the majority form oil in their cells (Xanthophyceae or Heterokontae), while oil-producing diatoms were also present, as was the oil-forming organism Botryococcus. Oil can be liberated from these organisms both by heat and pressure but it is highly unlikely, if not impossible, for sufficient oil to have come from this source in view of the quantity which has been subsequently produced artificially from this seepage area.[3]

Among other possible sources, the first one for consideration is the local Permian and Triassic section, which, as stated, is known to be 6,000 feet thick consisting of arenaceous redbeds laid down under arid, desert-basin conditions, an environment presumably completely inimical to oil formation. Upward migration from still deeper beds is a possibility as the whole region is strongly faulted, and the seeps occur in close proximity to several known fractures, but migration over such vertical distances through a predominantly sandy, porous section presents obvious difficulties even if suitable source rocks do underlie the Permian at great depth, a point which is quite unknown. It is thus seen that the origin of this Formby oil is completely unknown. The D'Arcy Exploration Company reports that it has produced 45,000 barrels from it and it thus obviously represents an accumulation of considerable size from such a shallow depth. It has been suggested that farther west beneath the Irish Sea a more favorable facies of the Trias may be present and that the Formby oil represents the concentration of whatever hydrocarbons have been formed in this unknown facies. This, however, is hypothetical and can not be proved at present.

JURASSIC IN SOUTHERN ENGLAND AND YORKSHIRE

The Jurassic rocks of England show many signs of the presence of hydrocarbon material, both solid and liquid, throughout the succession, including oil shales of varying quality at several horizons.

[3] F. W. Cope, "Oil Occurrences in South-West Lancashire," *Geol. Survey Great Britain Bull. 2* (1938), pp. 18–25.

In the upper part of the Lower Jurassic of Yorkshire there occurs a section of bituminous shale up to 100 feet thick, smelling strongly of oil, which includes many ammonites, whose internal chambers are filled with liquid oil. This can only have been formed *in situ*, and there is here an interesting occurrence of liquid oil and oil shales occurring in close proximity in the same horizon. The basal sandstone of the Middle Jurassic in this area is commonly oil-impregnated and yields a good chloroform color. In southern England the Lower Jurassic shows evidence of solid bitumen in joints and crevices in many places both at the surface and in borings.

In the Middle Jurassic of southern England an oil-impregnated grit in the Corallian beds on the Dorset coast is reported to have an oil content of 12.1 per cent and to give rise to an active seep at sea-level; bitumen staining is noted in the Oölitic limestones at depth in certain of the borings in the Kent coal field.

The Upper Jurassic in the south contains a notable oil shale in the thick marine Kimmeridge clay which runs to 60 gallons per ton, but with an economically unremovable sulphur content of 7 per cent. The overlying Portland sand in several of the Kentish borings had a strong bituminous odor, and in one of these has yielded a viscous bitumen which oozed in drops from joints in the sandstone. The Purbeck formation, at the top of the Jurassic, contains many oil showings ordinarily in the form of soft bituminous residues in creviced limestones, and bituminous limestones; and in the upper part of the Purbeck series occur some poor bituminous shales which on distillation yield a small quantity of tarry oil. It should be noted, however, that the Purbeck formation is almost entirely fresh-water in origin with a very subordinate proportion of marine beds.

The Jurassic, taken as a whole, gives therefore plentiful evidence of the presence of hydrocarbon material throughout the succession, although it is clear that the original source material has been extensively converted to form bituminous shales rather than free liquid oil.

LOWER CRETACEOUS IN SOUTHERN ENGLAND

This series of beds consists of thick alternating sands and clays of universally accepted fresh-water origin with no trace of marine influence, and yet they contain some of the most impressive indications of oil in quantity that occurs in the country, an occurrence which is difficult to reconcile with orthodox thought.

Near Pevensey, in Sussex, an asphaltic oil sand 8 feet thick occurs in the outcrop of the Tunbridge Wells sandstone formation of the Lower Wealden and contains 13.7 per cent of extractable bitumen by weight. This asphaltic oil sand covers a considerable area and presumably represents an oil concentration of some magnitude. Reports of liquid petroleum in wells drilled for natural gas in the Heathfield area of central Sussex are well known, and, although it is not possible to check such reports now, these occurrences are not considered impossible in view of what is known to be present in the near-by Pevensey area. Farther west, in Dorset, on the coast the Lower Wealden is known to contain several

closely associated and richly impregnated oil sands up to 12 feet in thickness over a distance of 2 miles.

In addition to these authenticated cases of oil, the occurrence of natural gas in small but usable quantity at Heathfield, in Sussex, is well known. Shallow wells drilled through the basal Cretaceous into the topmost beds of the Jurassic at the beginning of the century yielded gas showing 93.4 per cent of methane and 3 per cent ethane, and at one time more than 1 million cubic feet was produced daily for a short period. The origin of this gas is still a matter of doubt; it may be indigenous to either the Lower Cretaceous or the Upper Jurassic, or to both. A derivation from the abundant lignitic material in the Lower Cretaceous fresh-water sands and clays is sometimes advocated, but the small, but definite, ethane content of the gas seems to cast doubt on such an origin. Other cases of natural gas in smaller quantity are well known in central Sussex, all of which are definitely associated with Lower Cretaceous beds.

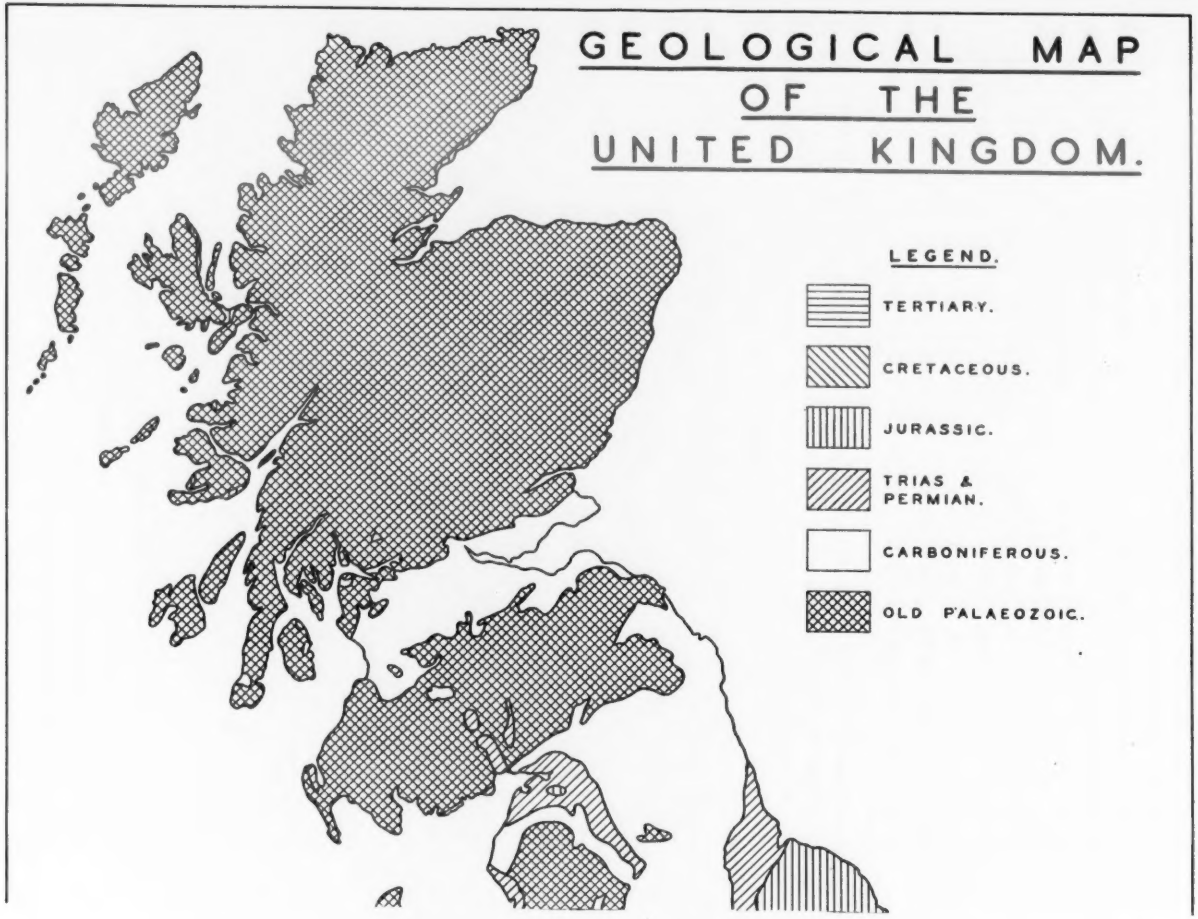
GENERAL

The foregoing notes show that the larger and best known oil indications in the British Isles are almost entirely associated with puzzling, and superficially impossible stratigraphical conditions, according to orthodox thought. The Trias oil impregnations and seeps occur in sediments deposited in an environment which appears incapable of promoting the oil-forming processes on the smallest scale. The Lower Cretaceous oil indications are associated with typical fresh-water beds, and the foregoing comments can be applied equally well to them, while the extensive Middle Coal Measure seeps, which indicate at least restricted oil formation over many hundreds of square miles of sediment, are derived from predominantly fresh-water beds deposited under conditions which should also preclude any oil formation. Finally, the Upper Jurassic Purbeck beds, in which bituminous residues are common, constitute a predominantly fresh-water section.

These four cases of oil indications form a large portion of the superficial evidence for the occurrence of oil in the British Isles, and yet they are all abnormal in type, so it is seen that the problem of oil finding in this region is not a simple one with oil restricted to normal marine sediments. The unorthodox occurrence of oil is a feature of the British picture, and it must be emphasized, therefore, that the evidence of the oil indications here described must be considered with great care before basing any workable conclusions on them.

Geological History of British Isles

It has been seen from the preceding section that there is considerable evidence for the presence of oil and bitumen over a wide stratigraphic range in this country. It has already been pointed out that much of this evidence is misleading if it be interpreted as directly indicating the presence of oil in large quantity in the formation where it is now found, and it is believed essential to return to the


GEOLOGICAL MAP
OF THE
UNITED KINGDOM.
LEGEND.
TERTIARY.
CRETACEOUS.
JURASSIC.
TRIAS & PERMIAN.
CARBONIFEROUS.
OLD PALAEOZOIC.

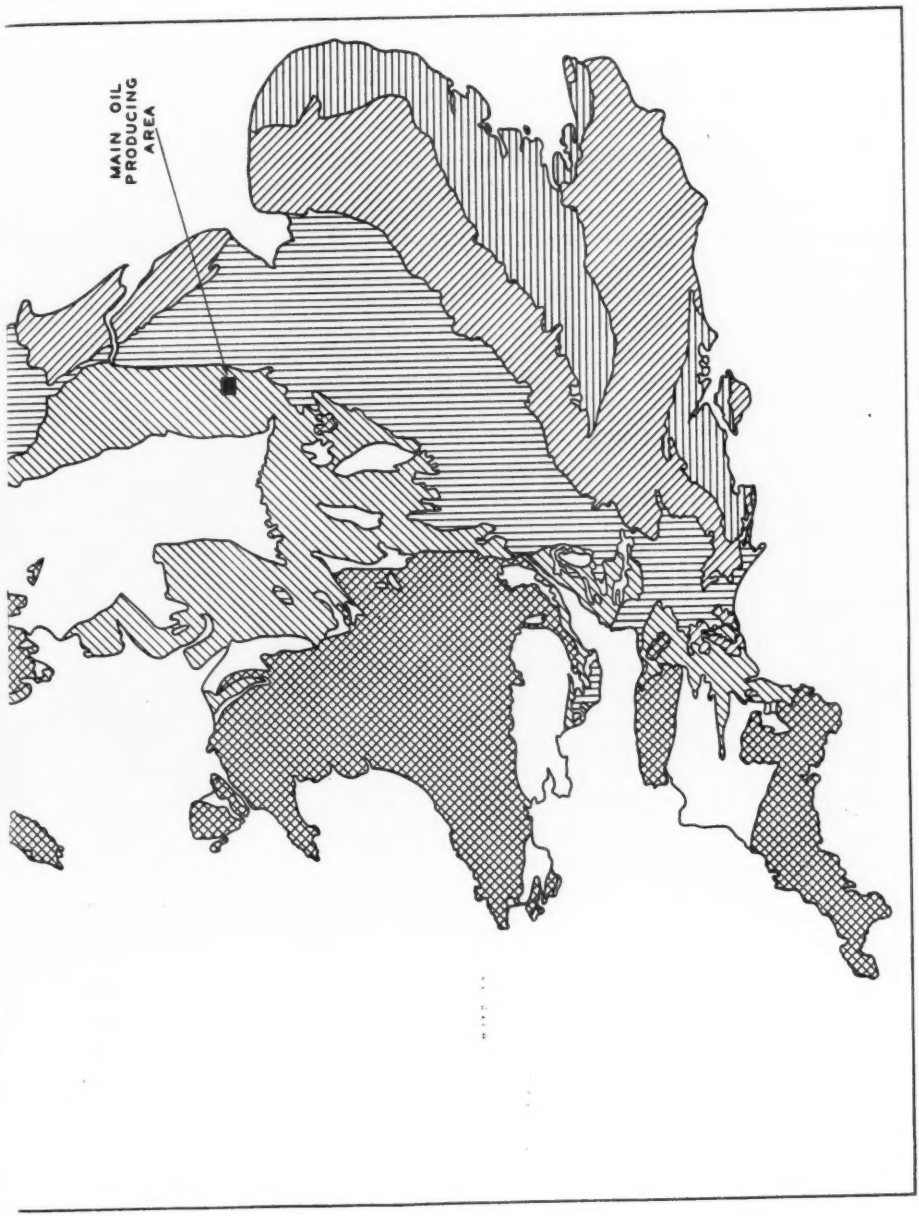


FIG. 3.—Geological map of the United Kingdom. (1 inch equals 54 miles)

geological fundamentals to discuss adequately the problem of British oil occurrence.

Of these fundamentals, the geological history of any region must take first place as primarily the question of the occurrence or non-occurrence of oil must be governed by the relative disposition of land and water which prevailed throughout the geological history, it being taken as axiomatic that oil is definitely the product of processes which are operative only in water, and almost universally brackish or salt water at that. With this general basic aspect of the problem is intimately connected the more detailed consideration of whether, or not, the marine areas in any particular period lay over unstable and mobile portions of the earth crust which might develop into downwarps, or geosynclinal belts, and which could provide accommodation for large masses of rapidly deposited sediments in environments suitable for the generation of oil. From a consideration of the geological history therefore, it should be possible to select certain periods during which paleogeography suggests the presence of favorable conditions for oil formation, while at the same time other periods might be dismissed as being of lower grading with little, or no, chance of including the desired environment.

In searching for favorable conditions the occurrence of thick sections of relatively shallow-water marine sediments, containing an alternation of lithologic type, particularly sands and shales, and giving evidence of rapid deposition over a subsiding area in water supporting an abundant assembly of animal life, would be given the highest grading. On the other hand, the occurrence of continental type beds laid down under conditions remote from marine influence, and in an oxidizing environment would be given the lowest grading, or might even be dismissed as being of no value whatever.

In between these two extremes occur many sedimentary developments whose grading would depend on careful weighing of the various factors such as geological, biological, and chemical, which have all contributed in a greater or lesser degree to its ultimate sedimentary character. This method of study can best be made in regions where considerable geological work has been done and much data is available; it is obviously not practicable, or at any rate not to the same degree, in undeveloped countries which are geologically little known. In Great Britain there is fortunately a large background of geological information against which to build up a picture of the geological history.

In the following notes the geological history of the British region is briefly summarized for each of the main divisions of the stratigraphic column. Reference to the paleogeographical maps for each period will assist in establishing a mental picture of the relative disposition of the land and water areas.

Pre-Cambrian.—Information is scanty and no accurate idea of the prevailing paleogeography can be formed.

Cambrian.—The British Isles lay wholly in a geosynclinal trough which stretched across the present Atlantic Ocean from Europe to North America. The Cambrian sediments which were deposited in the British area were wholly marine

and there is a general upward change in lithologic type from arenaceous beds, including conglomerates, to deeper-water shales and mudstones. This change in sedimentary type suggests a gradual deepening of the trough.

Ordovician.—The British region lay in the same geosyncline but the continued accumulation of sediments in this trough was accompanied by crustal movements and igneous activity, forerunners of the great Caledonian orogeny. Minor folding along northeast-southwest lines occurred at the beginning of the period.

There is a marked differentiation of the Ordovician sediments into a deep-water shale facies with a graptolite fauna, and a sandy facies with a brachiopod fauna which was probably laid down in shallow water round the edges of the enclosing landmass. By the end of Ordovician time the geosyncline had to a large extent been filled with sediments and crustal movements were becoming more intense, giving rise to relief by both folding and faulting.

Silurian.—The paleogeography of this period is still much the same as in the preceding periods, although the old trough was now finally silted up and renewed buckling culminated in the great earth movements of the Caledonian system. In the Lower Silurian there is still a well marked differentiation between a deep and shallow-water facies but this distinction tends to become more blurred as the succession is ascended and the highest beds are generally of a sandy or calcareous type. Silurian sediments are wholly marine and include graptolitic shales, coral limestones, shelly sandstones, and calcareous sandstones.

Caledonian orogeny.—The Caledonian earth movements which reached their height at the end of this period gave rise to lofty mountain ranges of Alpine dimensions in Scotland and northern England, while at the same time most of the British Isles was elevated into a land area with the exception of a strip along southern England and Ireland. The general direction of Caledonian structure is northeast-southwest and it is of interest that present-day earthquakes in Scotland are related to fault lines initiated at this time.

Devonian.—With the British Isles mainly a landmass there were two very distinct types of Devonian sediment. The Old Red sandstone facies of lacustrine habitat laid down in northern England and Scotland, and the marine Devonian facies in the southern strip deposited on the northern edge of the European sea. In certain areas there is conformity between the Silurian and Devonian, and the main Caledonian movements were not operative until mid-Devonian time.

Carboniferous.—This period opened with the Devonian sea of Europe transgressing northward over the now generally degraded continental mass of which the British Isles formed a part. A ridge of ancient rocks stretched across central England from Wales, giving rise to two main depositional areas—a northern and a southern. The British Isles forms part of the foreland to the Carboniferous geosyncline of central Europe, and deposition took place in interior-type basins many of which had considerable depth. The pre-Carboniferous basement moved intermittently during this period along lines of old crustal weakness, giving rise to considerable variations in thickness of deposition and sedimentary facies. In

the Upper Carboniferous occurred the general silting-up of the sea and the deposition of fresh-water sediments in thickly vegetated swamps and lagoons. The period closed with the Armorican, or Hercynian, orogeny which converted most of the British Isles into land.

Armorican orogeny.—The earth movements of this system uplifted much of northwestern Europe including the British Isles which, forming part of the foreland north of the central European geosyncline, was affected mainly by renewal of crustal movement along pre-existing trends in the basement, and only the extreme south and southwest part of the United Kingdom, fringing the edge of the geosyncline, suffered intense deformation along the typical east-west trend of the Armorican fold lines.

The Armorican movements impressed themselves strongly on the face of the country, and blocked out the main topographic features which are now present, though many of them have suffered further deformation through Tertiary movement. The British Isles were subjected to intense sub-aerial erosion and denudation during a lengthy period following the main Armorican folding, and a tremendous thickness of Carboniferous sediments was removed and redeposited as beds of debatable age before the oncoming of deposition which can be truly assigned to the Permian. In general the country had been well degraded during the equivalent of the Lower Permian time, and marine deposition took place during the Zechstein or Upper Permian.

Permian.—Much of the United Kingdom remained land throughout the period, and Permian deposition took place in two very different and separate environments. Eolian and lacustrine redbeds were laid down in isolated desert basins in the northwest while in the northeast semi-marine dolomites and evaporites were laid down in the western extremity of the saline Zechstein sea of Germany which formed a branch of the Tethys ocean.

Trias.—Conditions of deposition during this period were similar to those of the Permian with the area of deposition gradually increasing as the high topography was worn down. The Zechstein sea had withdrawn eastwards from its Permian limits, leaving in its place a series of shallow lakes, many of them saline, in a generally desert environment. The Trias sediments can be divided into a predominantly upper marl series and a generally sandy lower series, the former overlapping the latter considerably.

Jurassic.—In this period normal marine sedimentation again occurred in the region of the British Isles. There was a transgression of the sea from the south which spread over the now base-levelled Trias desert country. Slight flexuring of the sea floor early in the Jurassic led to deposition in connected shallow basins lying between positive rising axes over which sedimentation was much reduced. Uplift proceeded during the Upper Jurassic, and at the end of the period most of the country was again above sea-level with the exception of a fresh-water lake occupying part of southeast England and a narrow marine strip in eastern England. Jurassic sediments contain a large proportion of marine clays and shales,

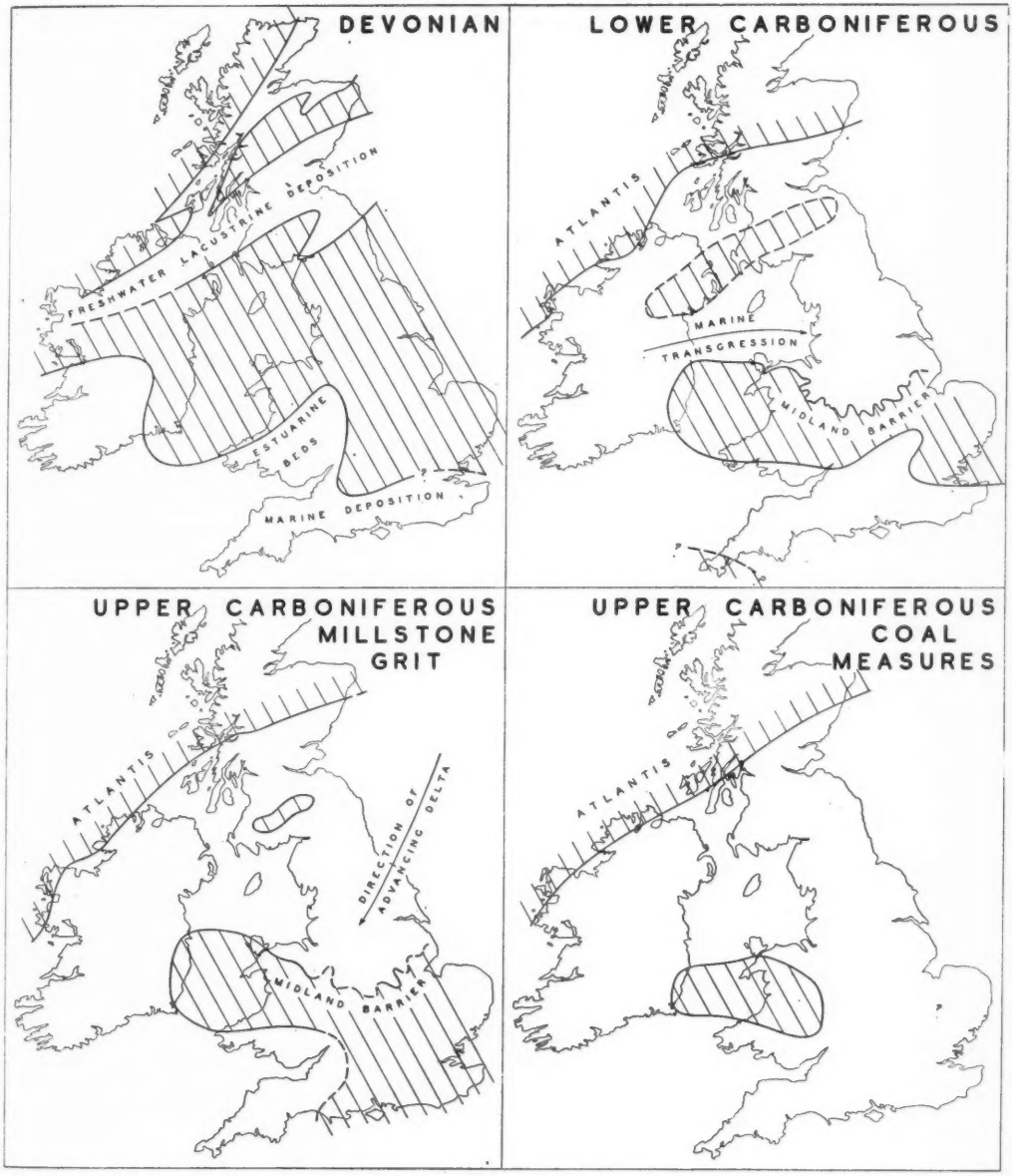


FIG. 4.—Paleogeographic maps of United Kingdom during Devonian and Carboniferous periods. (1 inch equals 180 miles)

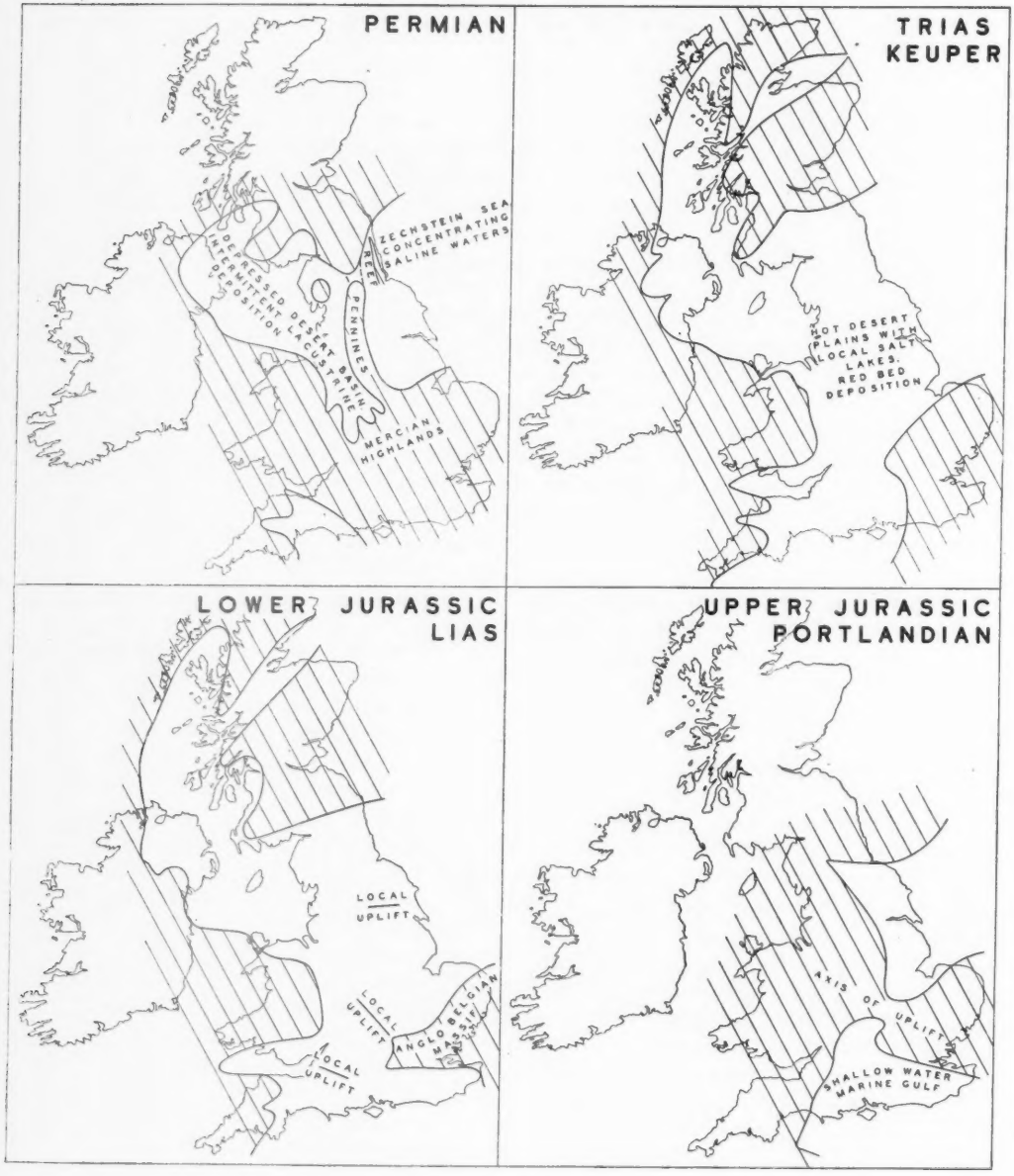


FIG. 5.—Paleogeographic maps during Permian, Trias, and Jurassic periods. (1 inch equals 180 miles)

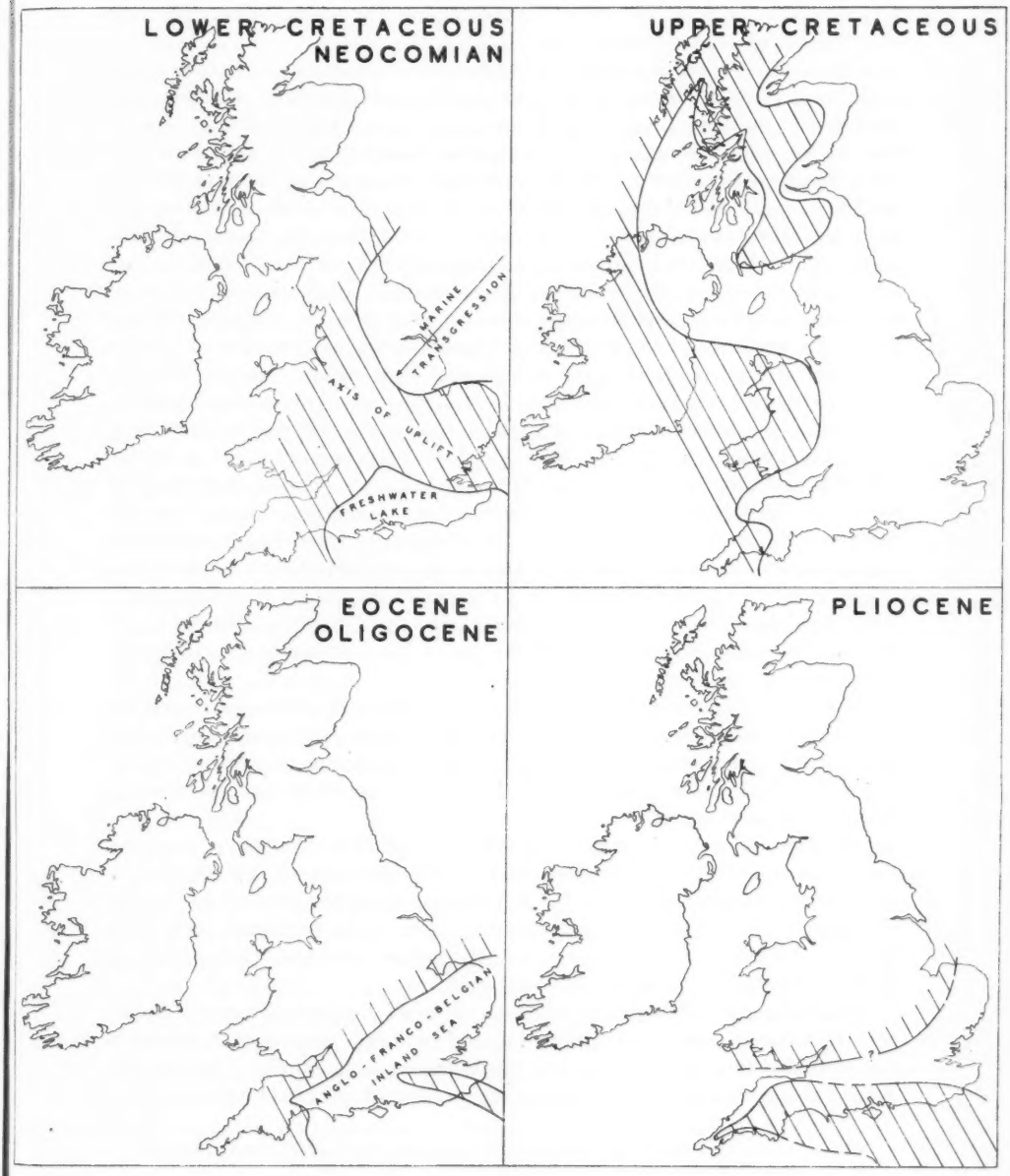


FIG. 6.—Paleogeographic maps during Cretaceous, Eocene, Oligocene, and Pliocene periods. (1 inch equals 180 miles)

with sandstones a generally minor, lithologic type. The whole period represents one complete cycle of sedimentation.

Cretaceous.—A marine invasion of the Jurassic land area was a feature of the early Cretaceous, although a considerable thickness of fresh-water sediments was deposited in southern England in the same fresh-water lake of Upper Jurassic time. In the Upper Cretaceous the whole of the United Kingdom was invaded by the widespread Cenomanian transgression and submerged except probably for the high country of Scotland and Wales. At the end of the Cretaceous there was again a general marine regression, and gentle crustal movements occurred, leading to slight uplift of the British Isles and tilting of the whole area toward the east without however, any intense folding. No movements comparable with those of the Laramide system of the western United States occurred in northwest Europe but in the British area a considerable thickness of Upper Cretaceous beds was removed by erosion. Preliminary movements occurred of structural features which were to be eventually developed in Miocene time as major tectonic units.

Eocene.—A gradual marine transgression took place over southeastern England which formed part of a depositional basin covering parts of England, France and Belgium. This was a relatively shallow inland sea connected at intervals to the great Tethys ocean which still extended over southern Europe and the Mediterranean countries eastward to the Himalayas. Intermittent subsidence and periods of quiescence led to a large-scale interdigitation of marine and estuarine sediments, it being possible to recognize five separate cycles of sedimentation.[4] Apart from southeast England, and parts of Scotland, the rest of the British Isles was land. At the end of the period the southern basin was largely silted up.

Oligocene.—The period opened with a fresh marine invasion over much the same depositional area, and thereafter the history of the Oligocene bears marked similarity to that of the Eocene with an alternation of marine with fresh-water, or brackish, sediment. The uplift of the British Isles by the Alpine earth movements brought this period to a close.

Miocene.—The Alpine orogeny converted the British Isles into a land area again and no sediments of this age are known in the country. The main earth disturbances lay south of Britain but this country lay sufficiently within the zone of movement for certain large-scale structural units to be developed, such as the Wealden anticline and the London and Hampshire synclines, while additional uplift of the Pennine ridge may have occurred.

Pliocene.—A local marine invasion of southeast England occurred, followed by a retreat of the sea northward and a gradual change upward from marine to estuarine and fresh-water beds. The Pliocene occupies a restricted area in east Anglia with a few widely separated outliers in parts of southern England.

[4] L. D. Stamp, "On Cycles of Sedimentation in the Eocene Strata of the Anglo-Franco-Belgian Basin," *Geological Magazine*, Vol. 58 (March, 1921).

GENERAL

The preceding summary brings out clearly the points of fundamental importance that only prior to the Devonian period was the general region of the British Isles part of a mobile belt of the earth's crust. From the Devonian onward to Recent time the history of this region has been one of alternation between continental and shallow-water marine conditions on the southern edges of a northern and western landmass which persisted through much of geological time, and is related in all possibility to the mythical continent of Atlantis. South of this lay the great ocean of Tethys, of which the present Mediterranean can be considered as a much reduced relic, and from this truly marine environment there extended northward great gulfs and bays over the stable mass of Atlantis. Crustal movements in this foreland, as such it really was, caused the constant transgression and regression of marine conditions depending on their positive or negative character; when uplift was the controlling factor so the original marine areas were severed from the marine ocean and converted into inland seas, saline lakes, and later fresh-water lakes and lagoons as the sea retreated still farther. Downwarping led to the transgression of shallow seas of shelf type and deposition proceeded in closed basins located on this foreland to Tethys, or else in basins which, although open to the sea, were still situated far from the mobile geosynclinal belt of thick and rapid marine sedimentation.

In these circumstances minor breaks in sedimentation are common, beds newly deposited are liable to be raised and brought back into the zone of submarine erosion and with generally shallow-water conditions the chances of the preservation of source material on any large scale are probably not of the best. Admittedly such conditions may give rise to ideal stratigraphic traps, but there is no adjacent zone of rapid sedimentation to provide oil.

Another equally important point is the occurrence of three major unconformities and erosional periods in the geological record which resulted from Great Britain being the meeting ground for the main orogenic movements which have affected western Europe. These movements not only uplifted the region under review but subjected it to intense folding and in many places widespread large-scale faulting, with accompanying induration and metamorphism of the sediments. Extensive denudation exposed successively older rocks to erosion and facilitated the flushing-away of any oil accumulation, either partially or wholly completed, which may have been present.

It is admitted that in many parts of the world, notably in the United States, unconformities have been fruitful geological features for the concentration of oil pools, but in the case of the major British unconformities it is difficult to visualize any geological conditions under which similar results might be achieved. Marine transgressions have indeed occurred at several time levels but some essential factor was missing and cases of "second crop" oil are not known.

The oil prospects in this country for any really large-scale accumulation must

therefore be limited by these two factors: (1) virtual non-occurrence of the accepted favorable marine environment, and (2) the incidence of three major breaks in sedimentation which offered substantial opportunity for the dispersal of any small-scale oil pools which may have accumulated during limited periods favorable for the generation of petroleum.

This somewhat pessimistic view appears inescapable after a more detailed study of the facts so briefly summarized, and while the possible presence of some small oil fields is not denied, as indeed has already been found, yet such occurrences are felt to be the result of local, rather than regional, oil-forming conditions whose preservation is the result of fortunate circumstance. The natural corollary of these remarks is that the discovery of oil pools in this country can only be the result of careful and often expensive exploratory effort, a fact which has been amply demonstrated during the present campaign. With the likelihood of there being any large-scale oil accumulations dispelled, the next step is to review the geological history again in order to select those periods which may have some prospects, if restricted, of containing suitable source beds and a favorable depositional environment for the generation and preservation of oil. As a result of such a review it is possible to classify the stratigraphical column according to relative favorability under the following headings.

Potentially Favorable Formations	*Potentially Unfavorable Formations*
Devonian (Marine facies)	Devonian (Old Red facies)
Carboniferous (Lower and part of Upper)	Upper Carboniferous (Coal Measures)
Permian (Marine facies)	Trias
Jurassic	Permian (Continental facies)
Cretaceous?	Lower Cretaceous
	Tertiary

It is thus seen that it is possible to eliminate a large portion of the British sediments as potentially unfavorable oil-forming rocks, from a consideration of the geological history. Such a classification on purely theoretical lines can not, of course, be taken as final, and further research into the nature of the source material of oil and the conditions of oil formation may provide information which will necessitate a complete revision of this arbitrary grading. As a basis for preliminary assessment, however, it serves a very useful purpose; results so far show that the only error appears to lie in too generous an allocation of potentially favorable rocks. This, however, is a fault on the right side and it ensures that no reasonable possibility has been overlooked.

The individual periods rated as potentially favorable are now discussed in more detail with particular reference to types of sediment, facies changes, and sedimentary environment where possible, to see if the necessary desiderata were indeed present.

Potentially Favorable Oil Formations

Old Paleozoic rocks

It is very probable that the Ordovician and Silurian periods included both conditions and source material which were favorable for oil formation in the

graptolitic shale facies of the central part of the depositional trough which merged shoreward into shallow-water sandstones and thus provided a theoretically ideal sedimentary relationship for oil accumulation. The only traces of oil in these beds are rare and insignificant, which is not surprising in view of the strongly folded and indurated character of these rocks which have been subjected to three major folding movements and exposed for long erosional periods in almost every part of the country. The Cambrian to Silurian section of the column can therefore be dismissed as a probable "has-been" with no prospects which can be considered apart from those attached to rank wildcatting.

DEVONIAN (MARINE FACIES)

Reference to the paleogeographical map of the Devonian period shows that southern England was submerged throughout the period beneath the Devonian sea of northwestern Europe, the coastline being indented by two large bays normally cut off from true marine conditions but subject to occasional invasion by the sea.

Actually the marine Devonian beds are only exposed in the extreme west part of England in the counties of Cornwall and Devon, and eastward from here they are completely covered and deeply buried by younger rocks, re-appearing at the outcrop in Belgium where they are well developed and yield a type section. Throughout the period there was an alternation of marine transgression northward followed by regression southward, each transgression reaching farther north, and in general there is a change in type of sediment southward to deeper-water varieties. The marine Devonian shows a wide range of sediments from grits and sandstones, limestones with reef developments, to shales and mudstones. At intervals these sediments are very fossiliferous and the succession seems one in which suitable oil-forming conditions may have been present. Under London this formation has been reached in certain exploratory bores and at Willesden showings of oil were recorded in some quantity during the drilling of a water well. Unfortunately the marine Devonian lay almost wholly within the northern limit of the Armorican earth movements, and has been so strongly folded and faulted that any capacity for oil retention it may have had was completely destroyed. The Willesden oil showings may have been preserved on account of their occurrence north of the limits of these earth movements.

It is believed, therefore, that the Devonian may originally have possessed some potentialities which have been eliminated by subsequent tectonic action.

CARBONIFEROUS

The first formation which has really favorable characteristics is the Carboniferous, a fact which is practically demonstrated by the abundant oil showings which occur within it.

The history of Carboniferous sedimentation is the story of the encroachment of marine conditions from Europe in the south onto the old Devonian continent

of which the British Isles form part of the southern edge, followed by the gradual recession of the sea and return of fresh water and ultimately continental conditions at the end of the period. As Britain formed part of the foreland north of the Carboniferous geosyncline of central Europe throughout the period, it was a relatively stable mass over which the depth of the epi-continental sea was never great. Thus there was no sagging mobile trough in which rapidly accumulated sediments were laid down, but, on the other hand, from Lower Carboniferous time onward there was basement movement, precursory of the post-Carboniferous orogeny, which led to differential movement within the foreland mass and allowed the accumulation of a considerable thickness of sediments in the relatively depressed areas which form local basins of deposition. From the evidence of the foregoing facts, therefore, the Carboniferous merits consideration as a period in which locally the conditions favorable for oil formation may have been present.

The Carboniferous system is divided into the following sub-units.

		American Equivalent
Coal Measures Millstone grit	Upper Carboniferous	Pennsylvanian
Carboniferous limestone	Lower Carboniferous	Mississippian

In view of the recent discussion on the classification of the Mississippian and Pennsylvanian rocks in North America[5] it is of interest to refer briefly to the stratigraphical relationship of equivalent Carboniferous beds in the United Kingdom. It appears that in America there is good reason to elevate the stratigraphical rank of these two divisions of the Carboniferous to that of separate geological systems, filling the gap between the Devonian and Permian.

In the United Kingdom there does not seem to be the same local geological basis for a re-allocation and grading of the two main divisions of the Carboniferous. It is well known that the boundary between the Upper and Lower Carboniferous is marked in many parts of the country—South Wales, Derbyshire, Yorkshire—by a distinct unconformity and undoubtedly there was a slight upward movement at the close of the Visean which may cause the succeeding Namurian to rest discordantly on the underlying beds. This relation, however, appears to be restricted more to the edges of the Lower Carboniferous basins of deposition, than to the center of these depressions where there is good evidence for a conformable passage from the Visean to Namurian with no apparent discordance, and certainly no trace of any angular unconformity such as can be observed in Derbyshire nearer the edges of the depositional area, where shales of the Upper "*Eumorphoceras*" zone rest on an eroded and pot-holed surface of Carboniferous limestone with a considerable gap in the succession caused by the absence of the Lower "*Eumorphoceras*" beds. In Lancashire and parts of Yorkshire, where the Namurian may be 6,000 feet thick, the Lower/Upper Carbonif-

[5] M. G. Cheney *et al.*, "Classification of Mississippian and Pennsylvanian Rocks of North America," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 2 (February, 1945).

erous boundary is placed within a uniform shale section and is determined by changes in the goniatite fauna, with the lowest beds present here which are missing in Derbyshire and also in Yorkshire.

It can be said therefore that no violent diastrophism separates the two divisions of the Carboniferous in the United Kingdom, and that while an unconformity is present at this level it is not widespread and is strictly localized, with an adjacent stratigraphically continuous section of Lower and Upper Carboniferous beds. This relation is admittedly a local one, and in Europe there is in many places a strong angular unconformity at the base of the Upper Carboniferous, as in Saxony; in England, however, there seems to be a different Carboniferous picture from that in North America and one which requires a different stratigraphic classification of the sediments embraced by the title "Carboniferous."

The Carboniferous sediments of the United Kingdom were deposited in two main areas separated on broad lines by a ridge of ancient Paleozoic rocks which stretched across the central portion of England from the Paleozoic massif of Wales. Connection between the two regions was established on the west round the Welsh landmass. Each of these two main areas can be subdivided into smaller provinces with specialized lithology and fauna, but for a general discussion of the Carboniferous the broad classification into a northern and southern region is sufficient.

LOWER CARBONIFEROUS—NORTHERN REGION

The development of the Lower Carboniferous in this region shows many variations in sedimentary types and there is a clear relation between any particular facies and its relative position in the sedimentary basin. Northward to the edge of the depositional basin there is a very marked change in environment from relatively deep water marine in south Yorkshire to estuarine and fresh water in north England and south Scotland. Southward to the Midland barrier of central England there is less variation, but there is a local fringing development of nearshore sandstone and conglomerate beds, derived from this peninsula which was only of local importance as a source of sedimentary material.

An important structural element in the northern region which exerted a continual influence on sedimentation was the so-called Rigid Block of Yorkshire, a fault-bounded massif of highly folded and consolidated old Paleozoic rocks which was only submerged late in Lower Carboniferous time and which received a specialized and attenuated sedimentary development. This positive element was bounded on the north and south by sagging negative elements, the Northumbrian and Craven troughs, respectively, in each of which a great thickness of sediments were laid down, in the former up to 8,000 feet of alternating fresh-water and estuarine beds, with some marine sediments in the upper part, and in the latter 6,000 feet of wholly marine shales and limestones. This massif is, therefore, seen to divide the northern Carboniferous region into two parts, a southern one pre-

dominantly marine in environment and the northern predominantly near-shore, with local facies variations within these main subdivisions. The following different environments of Lower Carboniferous sedimentations can be recognized, with their associated facies, commencing in the south and proceeding northward.

(*a*) *South Pennines.*—This environment has produced the most typical and well known development of Lower Carboniferous sediments—the Carboniferous limestone which gives rise to such rugged topography and scenic beauty in the Peak district of Derbyshire. This limestone is known to be more than 1,600 feet thick at the outcrop and has been proved for more than 3,000 feet in a boring in Staffordshire. Generally it is massive, thickly bedded, gray crystalline limestone with an abundant fauna of brachiopods, corals, *et cetera* at certain levels. Local chert development is common in many places and the limestone is in many places strongly dolomitized. In the upper part of the limestone a development of reef-knolls is observed, these consisting of thick lenses of very fossiliferous limestone containing both layers of broken shells and pockets of complete shells, commonly of brachiopods, the genus *Productus* being a common form. Corals are generally rare. Topographically these knolls are expressed as low hills or mounds, in many places with a pseudo-outward dip from the center of the knoll.

The environment suggested by these limestones is shallow-water marine on a slowly subsiding sea floor. The relatively pure character of the limestone and its faunal content indicates clear warm waters into which little detrital material was brought. Deposition was not rapid and organic material may not in these circumstances have had too great a chance of preservation. Structural data suggests that the center of the south Pennine region was undergoing uplift through most of Lower Carboniferous time with fringing reefs developed round the edges of this rising feature. According to Trask, these knolls should form a focus for local concentration of organic matter.

(*b*) *Craven Lowlands.*—Northward the Lower Carboniferous is next exposed in the Craven Lowland region 40 miles north of the last appearance of the South Pennine limestone facies, and it is immediately obvious that a different environment was in control here in view of the entirely different facies which is developed.

A thick section of dark shales with a typical goniatite and lamellibranch fauna—the Bowland shales—overlies a thick series of alternating shales and fossiliferous limestones with included reefs, the total thickness comprising at least 6,000 feet of sediments. There seems little doubt that this thick section was laid down in a locally sagging region compared with the facies deposited both on the north and the south. The depth of water was not necessarily much greater but deposition proceeded more rapidly with an alternation of lithologic type, a combination of circumstances which makes this Craven Lowland section a superficially attractive one. Oil showings are, however, virtually lacking apart from rare veins of solid bitumen in the limestone members, but against this negative evidence must be set the fact that this section has been deeply eroded, and exposed to denudation for a lengthy period, while abundant evidence of sharp folding

contemporaneous with deposition and giving rise to local emergence and disconformities is to be noted. In these circumstances it is considered that the lack of oil showings is not surprising though under suitable cover it is thought that this Craven section may originally have possessed considerable possibilities.

(*c*) *Yorkshire-Durham massif.*—Immediately north of the negative Craven element occurs the positive Yorkshire-Durham massif to which reference has already been made. Over this feature an entirely different facies of the Lower Carboniferous is developed, the edge of the massif forming the dividing line between this and the Craven section being marked by a strong development of reef-knolls. The thickness of the Lower Carboniferous is here only 1,800 feet, the bottom 400 feet being light gray massive limestone while the remainder of the section consists of a rapid alternation of limestones, shales, and sandstones known as the Yoredale series. This Yoredale series is typical of shallow-water marine conditions on an oscillating sea floor, and is so characteristic of similar sedimentation in other parts of northern England that the term "Yoredelian" is used to describe this type of facies. The Yoredale beds are responsible for the typical scenery of the Yorkshire dales, and over much of the massif the thick lower limestone member gives rise to typical "karst" landscape.

Here again is a marked change in environment related to the shallow-water conditions occurring over the massif, which was not submerged until late in Lower Carboniferous time, the alternation in rock types of the Yoredale series being a typical rhythmic succession related directly to the continued movement on the sea floor. This environment does not appear favorable for the preservation of organic matter, oxidizing conditions would be operative throughout the shallow depth of water in which these sediments were deposited, and the necessary rapid burial of source material would seem unlikely. It should be stated, however, that gas has been encountered at depth from the Yoredale series although surface showings of hydrocarbons are entirely lacking.

(*d*) *Northumbrian trough.*—Immediately north of the Yorkshire massif lies the Northumbrian trough in which at least 8,000 feet of Lower Carboniferous sediments occur with yet another facies change which shows the first indications of near-shore sedimentation. The whole section is decidedly more arenaceous and the lower part consists mainly of fresh-water and lagoonal deposits with but occasional marine incursions. In the upper part, the occurrence at regular intervals of thick marine limestones in a shale-sandstone succession is noted, with also the occurrence of coal seams pointing to the periodic cessation of subsidence and the building-up of sediments above water level. Westward, the Northumbrian trough deepens toward the Carlisle basin and a more marine facies of Yoredale type makes its appearance. The environment in which these beds were deposited does not appear attractive for oil generation. Alternating fresh-water and marine deposits do not suggest a rich organic content, particularly when the section contains a preponderance of sandstone members.

(*e*) *Midland Valley of Scotland.*—This bears a close resemblance to the North-

umbrian succession with, however, a greater development of coal beds and the occurrence of oil shales in the eastern part of the region. The maximum thickness is approximately 7,500 feet. The lower part of the section was laid down under near-shore lagoonal and estuarine conditions with occasional marine incursions. The section includes a thick alternation of shales and muddy dolomites (cement stones) followed by a section of rapidly alternating sandstone, shales, and limestones in which the oil shales occur. The upper part of the Lower Carboniferous is more marine in character than the lower, and includes many marine limestones; workable coal seams, however, occur at short intervals indicating an intermittent subsidence with periods of quiescence when the never deep near-shore water shoaled up with sediment. The whole of the Midland Valley facies was thus a near-shore development under conditions which do not suggest oil formation; the restricted occurrence of rich oil shales in a local basin of brackish- and fresh-water environment is interesting and comparison is invited with the wholly marine conditions in which the majority of the Jurassic oil shales of southern England were deposited.

The Lower Carboniferous in the northern basin of deposition thus shows both rapid changes in facies and thickness, and much of its development can be dismissed as being fundamentally unsuitable for oil formation. The Craven lowland section alone suggests an entirely favorable environment with the possibility that the South Pennine limestone facies may locally have given rise also to suitable conditions.

LOWER CARBONIFEROUS—SOUTHERN REGION

Information regarding the development of the Lower Carboniferous in the southern region is sporadic as this formation is deeply buried over much of it beneath younger beds, and it is only known at outcrop in southwest England and South Wales, while in southeastern England it is known from bore-hole evidence. Between these two areas its development is quite unknown. In South Wales the Lower Carboniferous shows a generally calcareous development, shallow-water limestones predominating, including oölitic, sandy, crinoidal, crystalline, and muddy types with calcitic mudstones and shales at certain levels. The whole succession can be classified as a major cycle of sedimentation with the main marine limestone phase between the upper and lower series of beds containing more detrital material. The maximum thickness recorded is 4,000 feet at the western end of the South Wales basin with a rapid thinning eastward within this feature. North and east toward the shore line the section becomes notably sandy, and an unconformity and erosional interval of some size occurs within the section.

In the closely adjacent outcrop near Bristol in western England a similar variety of limestone beds is developed with the dominant type a dark fossiliferous massive limestone of shallow-water origin; the total thickness in the Bristol area is between 2,000 and 3,000 feet and the continuous exposure of the limestones in the valley of the River Avon has become the classical section upon which the

zoning of the Lower Carboniferous throughout the country is based. Southward, the Lower Carboniferous in Devonshire is developed in the black limestone-shale facies typical of the Craven country farther north and was probably located in closer proximity to the main Carboniferous geosyncline.

The only other known developments of the Lower Carboniferous are in Kent where in certain coal borings it has been penetrated and found to be present as both massive limestone, and as interbedded black shale and limestone, while in a deep boring by the Gulf in Kent a massive crinoidal and oölitic limestone development was penetrated.

It is of interest that in the Bristol area there is evidence of a tilting toward the south in Lower Carboniferous time with near-shore sands and grits replacing calcareous beds at successively later stages farther south. These grits were originally correlated with the Millstone grit on a lithological basis, but paleontology has shown them to be truly Lower Carboniferous in age and the time equivalent of massive marine limestones in other parts of the country. This is a typical example of lithological boundaries transgressing time planes.

From the available data it seems that the Lower Carboniferous sediments in this southern region are more uniformly calcareous and show less facies variation than in the northern region, and limestones can be expected at depth in southern England below the cover of younger rocks.

MILLSTONE GRIT

This formation, which succeeds the Lower Carboniferous, is not strictly a true stratigraphical unit on a time basis throughout the country, but is rather a lithological development which bridges the gap between the cessation of the generally marine Lower Carboniferous sedimentation and the predominantly fresh-water conditions of the Upper Carboniferous Coal Measures. It may occur at different stratigraphic levels, according to local tectonic conditions prevailing in various parts of the country, and is broadly a sedimentary phase representing the silting-up of the Lower Carboniferous sea.

The paleogeography of the period shows that broadly the same disposition of land and water prevailed as in Lower Carboniferous time. The Midland barrier of ancient rocks still separated a northern and southern area of deposition but the source of supply of the sediments was entirely different in the two regions. In the north the Millstone grit sediments were brought in by a great river flowing from a northern landmass into the Lower Carboniferous sea, which was by now no longer a transgressive element and was indeed starting to withdraw. In the southern region, the Millstone grit of equivalent age to the northern sediments which is present appears to be derived from the nearby landmass of the Midland barrier. The type and thickness of the Millstone grit section causes its formation to be considered as a possible oil source and actually the only fields of any size which have been found in this country are producing from it.

Northern region.—The Millstone grit is only recognized as a clear stratigraphi-

cal subdivision based on paleontological evidence in the southern part of the northern region of deposition particularly in the counties of Yorkshire, Lancashire, Derbyshire, and Staffordshire (the Midlands). In this Midlands region it is present as a definitely younger formation than the Lower Carboniferous, from which it is separated by an unconformity in many places, and it is not a local sandy development of the Lower Carboniferous as is the so called Millstone grit of western England. The limits of the formation are defined by a typical goniatite sequence which subdivides the succession into four zones, the change from the Lower Carboniferous to the Millstone grit being based on the appearance of the genus "*Eumorphoceras.*"

Northward from this Midland region the Millstone grit undergoes great changes in thickness and lithology at the edge of the Yorkshire massif which here, as in Lower Carboniferous time, exerted a controlling influence on sedimentation, and marks the northward limit of the typical Millstone grit development. Northward over the massif the Millstone grit thins in a short distance, the upper beds overlap onto the lower, and there is a facies change of the lower part of the section to a more Yoredelian type of bed. Northward also into Northumberland and Durham the Millstone grit can not be separated as such from the Yoredale-like beds of the upper Lower Carboniferous and although some grits occur which are allocated to this formation on lithological grounds, yet it is doubtful if these are the true time equivalent of the Midland deposits. Unfortunately the biologic environment in northern England did not favor the continued existence of goniatites; hence, the extension of the typical goniatite horizons northward is not possible.

In the Midlands basin of deposition the Millstone grits show perfect conformity with the underlying Lower Carboniferous in Lancashire and it here attains a thickness of 5,000 to 6,000 feet. In Derbyshire, the lowest beds of the Millstone grit are the Edale shales lying unconformably on the Carboniferous limestone, the available evidence suggesting a non-sequence. The Edale shales consist of paper laminated, dark gray and black shales with bands of black, bituminous, muddy nodular limestones or calcareous mudstones which are common in the basal portion of the section and become increasingly rarer higher in the sequence. These calcareous mudstones include many concretionary masses containing goniatites which, when broken open, show liquid oil in their internal chambers. This clearly indicates *in situ* formation of oil and the whole aspect of these marine Edale shales showing an alternation of shales and impure limestones with bituminous content, strongly suggests an oil source formation. In Lancashire, similar bands of nodules, including goniatites with chambers full of oil, are included in a higher zone of the Millstone grit compared with the Derbyshire occurrence.

The sedimentary environment in which the Millstone grit was deposited shows a gradual change from marine to deltaic as the Carboniferous sea became increasingly filled with sediment, and it is thought that the upper part of the section can be dismissed as a possible source, although the thick deltaic grits and

sandstones which comprise a major portion of it, provide excellent reservoir capacity. Deltaic deposition in shallow water subject to current action, is far from the ideal condition for the accumulation of much organic material, and subsequent conversion to hydrocarbons, and it is a known fact that the organic content of deltaic sediments is markedly lower than average. The predominantly marine shales which initiated the Millstone grit deposition imply, however, a very different set of conditions; slight folding at the end of Lower Carboniferous time had given rise to locally deep marine basins and in these features the deposition of fine-grained sediments suggests almost optimum oil-forming conditions.

The thickness of the Millstone grit shows considerable variation and general isopach lines over the Midland region are shown on the attached map (Fig. 7). A maximum thickness is recorded in Lancashire which appeared to be the center of deposition on which thinning took place in all directions. Such thinning is composed of both regional and local influences, the latter being caused by tectonic movements which were operative at the end of Lower Carboniferous time and continue into the Upper Carboniferous; folds were in process of rising along old rejuvenated basement trends and Millstone grit sediments are known to be thin or partially missing over many such anticlines, while full sections are presumably present in the intervening troughs. This contemporaneous movement with sedimentation is probably of paramount importance in controlling the location of the present oil pools in the Millstone grit.

The Millstone grits are uniform in type and show a preponderance of black marine shales with impure calcareous mudstones in the lower part, while higher in the succession the proportion of marine shales becomes increasingly less, and marine fossils are restricted to relatively rare bands. Deltaic and estuarine shales with thick coarse grits containing much decomposed feldspar constitute the upper part of the section, with here and there thin coals and fireclays which denote a temporary build-up of sediment above water level. The deposition of the thin marine bands proceeded over a lengthy period according to fossil evidence which shows that complete changes in goniatite lineage can take place in these very thin bands, while on the other hand the coarse grits and mudstones carried in by the northern river were by comparison deposited rapidly.

The succeeding Coal Measures overlie the Millstone grit with perfect conformity in the Midlands to a maximum thickness of more than 5,000 feet and the latter formation was not subjected in general to deep erosion immediately subsequent to deposition. In post-Carboniferous time much of this cover was removed by Permian erosion, but by that time presumably the formation and accumulation of any Millstone grit oil had taken place and the thickness of overlying sediment was of less importance so long as there was sufficient to form an efficient seal.

Evidence is coming to light to indicate movement of certain anticlinal axes during Coal Measure time, and the possibility is present that an erosion period of some magnitude may be present within the Coal Measures over these axes,

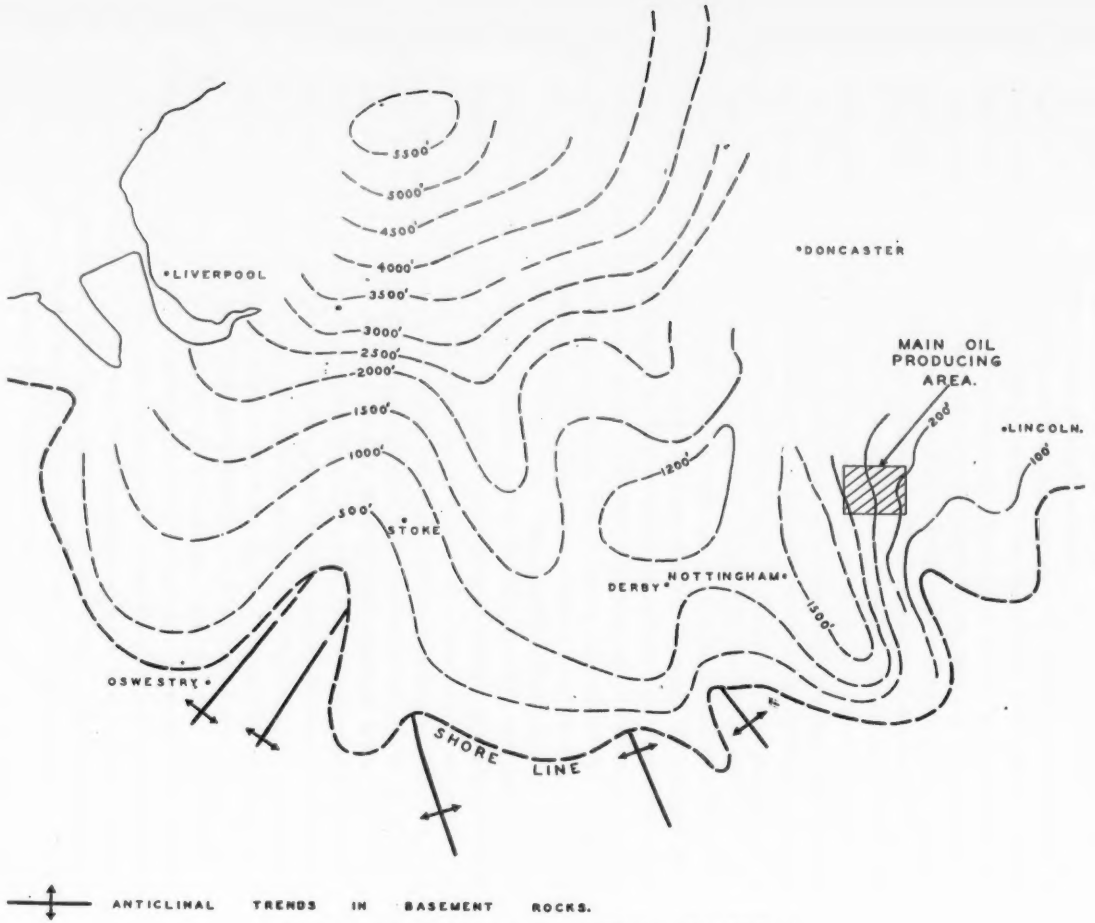


FIG. 7.—Generalized isopach map of Millstone grit in Midlands.
(1 inch equals 20 miles)

possibly cutting down into the Millstone grit with consequent danger of dispersal to any oil accumulations therein. Such a tectonic happening is of considerable importance in assessing the prospects of Carboniferous structures and further data are needed to outline such areas of intra-Coal Measure uplift.

Southern region.—The deposition of the Millstone grit in the southern region is, like the Lower Carboniferous, only known at scattered points on account of the cover of Mesozoic and Tertiary rocks. In south Wales a section which contains the paleontological zones of the Pennines Millstone grit is present up to a thickness of 2,000 feet, but it presents different lithological characteristics and thick quartzites and siliceous sandstones are the typical development for the arenaceous beds. The lower part of the section, equivalent to the bituminous Edale section of the Midlands, is represented by a predominantly quartzitic phase with only subordinate shale. Succeeding this is a section of dark shales with some grit bands which in turn is overlain by a thick sandstone development. These sediments were laid down in relatively shallow water on the continental shelf and were derived from the landmass of central Wales; marine fossils are common but, as in the Midlands, fresh- and brackish-water forms become increasingly abundant in the upper part of the succession. It would seem that some prospect of oil formation could occur in this section, but the high proportion of sandy beds could be an adverse factor.

Elsewhere in the southern region the Millstone grit is represented in Cornwall and Devon, but otherwise appears to be missing or represented lithologically by a sandy facies of the Carboniferous limestone. In Kent the Coal Measures rest at depth on an eroded surface of Carboniferous limestone and no Millstone grit is present, either by reason of non-deposition or subsequent erosion. In Sussex borehole evidence has shown Jurassic rocks resting directly on the Lower Carboniferous. Hence, the presence of the true Millstone grit over much of the southern region is open to doubt and it is probable that much of this territory was elevated at the end of Lower Carboniferous time and either only received sediments locally and intermittently during the Millstone grit, or else received none at all.

PERMIAN

The Permian is included in this discussion of potentially favorable source rock mainly by reason of the close resemblance between one particular facies of the British development and a similar development in Germany which is productive of oil.

This formation in the British Isles is present in two different facies typical of depositional environments which were entirely dissimilar. Reference to the paleogeographical map for this period shows that over northwestern England and western Scotland the Permian sediments were laid down in a series of possibly connected desert basins lying west of the Pennine uplift. These beds consist of red continental-type sandstones and marls with thick conglomerates and breccias in certain areas, with clear evidence of eolian deposition in parts of the section

which shows a mazimum thickness of 3,000 to 4,000 feet. The depositional environment of these beds is clearly such as to preclude them as potential source formations and they need not be considered further.

The other type of Permian occurs in eastern and northeastern England and is typically developed as a dolomitic limestone. This facies was deposited in the extreme western limit of the Zechstein sea of Germany, part of which extended from the present European mainland as far west as the Pennine uplift which was sufficiently developed by that time to form an effective land barrier, though there is evidence to show that it was breached on occasion, as shown by the occurrence of thin, dolomitic limestones in the otherwise continental succession on the west side of this ridge.

In Germany the rocks deposited in the Zechstein sea include porous dolomitic limestones and bryozoan reef limestones from which commercial oil supplies have been obtained in Brunswick. Sediments of equivalent age and similar lithology occur in the Magnesian limestone in England and by analogy, therefore, this formation merits some consideration.

This Permian section shows a maximum thickness of 800 to 1,000 feet in Durham and includes some 800 feet of magnesian limestone which is not a true dolomite but is a variable mixture of the two carbonates deposited in concentrating water. The lower part of the limestone is a bedded non-fossiliferous rock which in Durham is succeeded by a bryozoan reef several miles wide and some 400 feet thick at its maximum. This reef development is richly fossiliferous and is directly comparable with the producing beds in Germany with which no doubt it at one time was connected over the present site of the North Sea. It is flanked by bedded dolomites on the west and brecciated limestones on the east. These breccias are formed *in situ* and show a great variation in type of fracture and size of fragment, the volume increase occasioned by the hydration of included anhydrite being believed responsible for much of the shattering of the original rock. The top part of the Durham development includes massive oölitic dolomite, and a most striking concretionary limestone consisting of spheroidal concretions up to 3 feet in diameter, which is known as the Cannon Ball limestone. Overlying this is a thick evaporite and marl section which, although classified as Trias, was more related depositionally to the Permian.

Southward the Permian section soon shows changes in type, and in Yorkshire both at outcrop and in test wells drilled for oil, the reef development has disappeared and the Magnesian limestone is developed as a relatively close textured dolomitic rock with no trace of the brecciated limestones. This more normal type of limestone is split by an evaporite section of salt and anhydrite and the entire succession thins southward and dies out near Nottingham.

The reef facies of the Magnesian limestone which is associated with the Permian oil production in Germany has thus a very restricted occurrence in this country. Dry gas in some quantity has, however, been found on structure in the Yorkshire basin in the dolomitic limestone and showings of gas commonly occur

in salt bores in the overlying evaporite section. Slight showings of a black oil have been recorded in two of these bores, one at the unconformable contact of the Permian and Carboniferous, and the other near the base of the Permian, but in such circumstances there is a dual possibility for the origin of such oil, with a Carboniferous source very probable.

The environment in which the Magnesian limestone was deposited is that of a land-locked inland sea into which little land débris was carried. Concentration proceeded until precipitation took place in saline waters which in general did not support an abundant fauna. Such an environment suggests relative slow deposition under tranquil conditions with chemical conditions which finally were very different from those prevailing in normal marine waters; the supply of organic material would not be abundant in view of the restricted and specialized fauna. The association of oil with bryozoan reef limestones would, therefore, appear to be primary if the possibility of migration from other sources be excluded, so that altogether this formation does not appear to be one likely to produce much oil. It must be borne in mind, however, that these highly concentrated waters must have given rise to chemical conditions under which organic matter might decompose along rather different lines from such processes on normal sea bottoms, and bacteria adapted to the specialized conditions might be operative in attacking whatever organic material was present.

JURASSIC

This period ranks with the Carboniferous as being theoretically the most favorable for the production of oil, and at the start of the present campaign it was possibly rated the higher of the two.

The geological history of the Jurassic period in the United Kingdom is, in effect, the story of a complete major cycle of sedimentation commencing with the northward transgression of an arm of the great Tethys ocean, and ending with the retreat of the sea and the emergence of this region as a land area once again with the exception of a large, fresh-water lake covering southeastern England. During this period the sea was seldom deep and deposition proceeded, as in Carboniferous time, on a shelf area bounding Tethys and formed by the southern edge of the stable continental mass of Atlantis. This stable mass underwent no strong downwarping and geosynclinal depressions were absent, but, on the other hand, slight periodic posthumous movements of uplift and downfolding along old basement trends took place which led to deposition within local basins, with facies changes and variations in thickness a marked feature.

The landmass onto which the Jurassic sea transgressed was generally of low elevation after the virtual peneplanation which had occurred in Permian and Triassic times; hence, the general grade of sediment derived from this continent must have been fine, with coarse-grained sediments virtually lacking; river velocity must have been low and hence near-shore deposition of fine sediments must have been the depositional characteristic of this period. Shallow-water clays and

mudstones form a large proportion of the Jurassic section and near-shore shelly and oölitic limestones comprise the greater part of the remainder. Life was abundant throughout the period, judged by the richness of the fauna contained within these sediments.

The two thickest developments of the Jurassic occur in Yorkshire and in, southern England, in the former locality 3,000 feet being present and in the latter a maximum of 4,000 feet. The Lower Jurassic is composed mainly of dark blue and gray shales with subordinate sandy clays and sandstones, a feature of the lower part of this section being the rapid alternation of dark shales and impure limestones. Slight uplift contemporaneous with deposition took place over certain axes which are shown on the paleogeographic map, and these movements continued into the Middle Jurassic.

Uplift in northern England during the Middle Jurassic led to the deposition of a different facies from that developed in the south. In Yorkshire deltaic conditions set in, which were comparable with the Coal Measure environment, and the Middle Jurassic consists of interbedded shallow-water shales and sandstones with coals and impure limestones, current bedding being a feature of these sediments. In the south, however, the growth of coral reefs was a feature of this period and these in turn supplied the material for the thick oölites and rubbly limestones that form a large proportion of the Middle Jurassic section. The close of this division of the Jurassic saw gradual submergence and the return to uniform marine conditions over the whole region.

In the Upper Jurassic, clays form a preponderant part of the section. The lowest bed is the Oxford clay, a stiff fossiliferous clay which has a basement bed of sand. Succeeding this is the Corallian, an interesting alternation of coral limestones and calcareous grits, which indicate a temporary cessation of muddy deposition though locally in the Midlands this formation is represented by a black gypsiferous clay. A return to fine-grained deposition is seen in the Kimmeridge clay, up to 1,200 feet in thickness, which is a dark marine clay containing calcareous nodular bands and is widely distributed over the whole country. This formation is very fossiliferous with an abundant and varied ammonite fauna, it is also bituminous with a particularly rich oil shale in the upper portion. This clay grades up in southern England into an arenaceous phase—the Portland sands—and the presence of this sand in close proximity to the marine bituminous clay led to the belief that this would be a good prospect on structure for oil pooling.

Subsequent to the Kimmeridge clay deposition there was uplift across the center of England along a northwest, southeast line corresponding in all probability with an old basement trend which has shown recurrent movement from the earliest geological time. This uplift divided the Jurassic depositional area into a northern and southern portion. Little is known about the latest Jurassic sediments in the north as they were removed by erosion in early Cretaceous time, but in the south there was gradual isolation from the main ocean, and the topmost Jurassic, the Purbeck beds, consists of alternating estuarine and fresh-water shales and

limestones with occasional land surfaces indicative of temporary emergence. Infrequent beds containing marine fossils indicating marine incursions of the Purbeck lagoon are found, especially in the Middle Purbeck, but the Upper Purbeck is exclusively fresh water and contains the celebrated "Paludina" limestone quarried extensively for building stone. The Jurassic closed, therefore, with the British Isles once again predominantly a land area, with a lagoonal area over the southeast which had become a fresh-water lake by the end of the period.

The condition of deposition and the type of sediment of the Jurassic section suggests that locally at any rate the necessary desiderata for oil formation must have been present. Shales and limestones of near-shore facies containing an abundant fauna and accumulating in locally subsiding depressions under reducing conditions would appear to be the ideal sediments for the production of some oil and yet the Jurassic prospects have been completely disappointing. This question will be discussed again in the final summary, but it is relevant to emphasize once again the occurrence of oil shales, many of considerable richness, at various horizons in the Jurassic section, an occurrence which may afford a clue to what is otherwise a somewhat paradoxical state of affairs.

WEALDEN (LOWER CRETACEOUS)

This formation is not theoretically favorable on account of its fresh-water character but, in view of the impressive evidence of oil which it contains, it is thought that it should be among those considered as a possible source sediment. Lower Cretaceous deposition continued in southern England without a break in the same fresh-water lake in which the topmost Jurassic beds were laid down, and the Wealden sediments which form the main part of this section consist of a predominantly clayey upper portion, the Weald clay, and a more sandy lower portion, the Hasting sands, which are themselves subdivided again into various sand and clay members. The maximum thickness of the whole Wealden section is 2,500 feet and these fresh-water beds are typical lacustrine sands and clays with some fresh-water limestones; the sands are ordinarily soft and fine-grained with clay intercalations while the clays are stiff, blue and brown beds most of which are unfossiliferous. Ripple-marked sandstones are common pointing to the shallow-water nature of these beds. The whole Wealden section is not fossiliferous except at widely separated horizons such as the "Paludina" limestones, and certain sandstones rich in reptilian remains. Plant remains and lignite also occur commonly in some abundance in the Lower Wealden.

The Wealden lake must have been a continuously sagging area to accumulate such a thickness of sediments, and ultimately there was a return of the sea from the south which transgressed over most of southern England and joined a southward transgressing sea from eastern England. The so-called Lower Greensand of Aptian age was deposited by this transgressing sea, but generally there is little discordance between this and the underlying Wealden beds as the movement was gentle and gradual. The Lower Greensand consists of a varied sequence of shallow-

CALEDONIAN FORELAND
LARGE SCALE THRUST FAULTING.
ZONE OF CALEDONIAN OROGENIC MOVEMENTS IN SILURIAN-DEVONIAN TIME ALONG N.E.-S.W. TRENDS.
CALEDONIAN OROGENY?
ZONE OF CHARNIAN OROGENY IN PRE-CAMBRIAN ALONG NW-SE. TRENDS EXTENT UNKNOWN.
SOUTHERN LIMIT OF
NORTHERN LIMIT OF ARMORICAN MOVEMENTS
ARMORICAN FORELAND
PALAEO-EUROPE
MESO-EUROPE
ZONE OF ARMORICAN OROGENIC MOVEMENTS IN POST-CARBONIFEROUS TIME ALONG E.S.E. TRENDS.

FIG. 8.—Tectonic framework of United Kingdom.
(1 inch equals 75 miles)

water marine sands and clays containing a marine fauna in marked contrast to that contained in the Wealden beds.

Such is the Lower Cretaceous, predominantly a shallow-water non-marine lacustrine period isolated from all marine influence, which would not superficially appear to include any environment favorable for promoting the oil-forming processes. Organic material was probably plentiful at certain horizons but under the obvious oxidizing and non-saline conditions of the Wealden lake, its conversion to hydrocarbons is difficult to visualize. On the other hand the formation of hydrocarbon-like products in fresh-water lacustrine environments is an established fact, and Twenhofel[6] has described certain lakes in Wisconsin of post-glacial age from which sediments have yielded on destructive distillation 15 to 25 gallons of oil per ton, a figure which is comparable with the yield of many oil shales in the world. The oil in these sediments is, of course, probably a primary product of the life processes of certain fresh-water algae, and as such can not be directly compared with normal petroleum believed to be the product of chemical action or bacteria subsequent to the death and burial of vegetable and animal life in sediments. Nevertheless, it is not in the realm of fantasy to suggest that conditions in the Wealden lake may have promoted the existence of oil-forming organisms and that in this particular case, free oil was produced instead of hydrocarbon-containing rocks. It is open to question whether chemical analysis could differentiate, after long exposure to weathering, between an inspissated so-called normal crude and an inspissated oil derived directly from organic life.

Tectonic Framework of United Kingdom

The structural framework of the United Kingdom is complex and bears the tectonic imprint of all the major mountain-making periods during which vast crustal movements and earth disturbances were in progress.

This country is located in a zone of the earth's crust where the full force of at least two, and possibly three, of the great orogenic movements were effective, and certain regions are seen to be dominated by the structural grain imposed by one or other of these movements. It is possible to trace fairly closely the boundaries and limits of folding within which each of these earth movements were operative, and it is of interest to note that generally the center of each earth storm appeared to move successively southward with decreasing geological age until during the latest orogenic phase, that of the Alpine movements culminating in late Tertiary time, the United Kingdom lay north of the main focus of deformation and was affected only by the partially spent crustal stresses which were most strongly effective in central Europe. This may only be a coincidence of course, but if the earliest orogeny in pre-Cambrian time of which little is known is neglected, there is a clear case for a well marked shift southward of the zone of maximum crustal stress.

[6] W. H. Twenhofel, in *Report of a Conference on the Origin of Oil*, conducted by Research Committee of Amer. Assoc. Petrol. Geol. (1941), p. 24.

The various periods of orogenic movement in the United Kingdom can be briefly summarized as follows.

Orogeny	*Culmination of Movement*	*General Fold Trend*
Charnian	Pre-Cambrian	NW.–SE.
Caledonian	Silurian—early Devonian	NE.–SW.
Armorican	Pre-Permian	E.SE.–W.NW.
Alpine	Miocene	E.–W.

Considering the structure of the United Kingdom in detail from the view-point of oil accumulation, an acquaintance with the main facts of these orogenic movements is of relevance in understanding the disposition of the component structural units and their relation to one another.

CHARNIAN OROGENY

Little is known about the details of the pre-Cambrian earth movements in the United Kingdom, although undoubtedly they were widespread and on a grand scale, and rocks of this age are only exposed at scattered and isolated points. In central England, however, a large tract of pre-Cambrian rocks is exposed in the Charnwood Forest region of Leicestershire and are folded along northwest-southeast lines which are believed to ante-date the later Caledonian movements. The orogeny which gave rise to this structure has been termed Charnian from its association with Charnwood Forest, and the same term is applied to describe any structural line which is generally disposed northwest and southeast. Pre-Cambrian folding and earth movements may seem at first sight rather irrelevant in a discussion on oil prospects, but actually this is not so as the considerable volume of data available on structural trends in the buried Carboniferous east of the Pennines shows these to be all variations of the Charnian direction with little traces of any of the later directions of movement, and it seems clear that this pre-Cambrian orogeny has impressed a dominant trend in the earth's crust in the region of Nottinghamshire and south Yorkshire along which posthumous folding has taken place during each of the succeeding periods of movement. The original extent of this zone is untraceable, but stratigraphical evidence points to irregularities in Lower Cretaceous sedimentation over probable Charnian axes as far south as Bedfordshire, while the disposition of the Paleozoic floor of southern England indicates the presence of a ridge trending southeast as far south as the Thames Valley. Northward there is evidence for buried Charnian trends up to the edge of the Craven Lowlands in Yorkshire where there is a marked change in the direction of folding. Elsewhere in England the Charnian trend may be recognized along the northeast edge of the Cheshire basin where large-scale tension faults downthrowing thousands of feet are no doubt associated with Charnian lines of weakness at depth.

The limits or boundaries of the Charnian earth movements are not known but there seems reason to believe that much of the Midlands and possibly northern England lies in what was once the zone of movement, and a guess may be

hazarded at a belt of folding northwest and southeast through the Midlands and extending for an unknown distance in either direction. It is of interest that the largest producing field in the country lies on a north-northwest trend which is probably the result of posthumous folding during Armorican times along a modified Charnian trend.

CALEDONIAN OROGENY

This movement is termed Caledonian on account of its paramount influence on the tectonic build of Scotland whose present topography even now is determined by geological structures developed during this orogeny.

Knowledge of the extent and limits of the Caledonian earth movement is reasonably full, and it is possible to visualize with some clarity the disposition of the geosyncline which was the cradle of these forces. In the earlier consideration of the geological history of the United Kingdom it may be remembered that throughout the Lower Paleozoic a geosynclinal trough stretched across the present Atlantic Ocean from North America to western Europe, and it was the silting up and buckling of this trough which gave rise to the Caledonian movement.

In northwest Scotland it is possible to recognize in a coastal strip of pre-Cambrian rocks the rigid foreland (Atlantis) against which the Lower Paleozoic sediments in this geosyncline were thrust, and the northwest highlands of Scotland are formed by a succession of overthrust sheets comparable in structural complexity with parts of the present Alps. Undoubtedly the original mountains formed at this time, known as the Caledonides, must have been of size and extent equal to and possibly greater than the Alpine chains as the considerable mountains now seen can represent only the vestiges of the original uplift after continual exposure to erosion since Devonian time. Intensive Caledonian folding of Lower Paleozoic sediments can be recognized in southern Scotland, the Lake District, and north and central Wales, and although the overthrusts and nappes of the highlands are no longer a feature yet movements were strong in this region, and isoclinal folds are typical together with violent metamorphism which has imparted a slaty cleavage. In eastern England the Caledonian movements are in general of little importance and do not appear to have been sufficient to dominate pre-existing Charnian trends.

The southern edge of the Caledonian folding in England is not known. Eastward in Scandinavia, however, this limit is clearly delineated by the thrusting of Lower Paleozoic rocks southeastward over the Baltic shield, which here acted as did the continent of Atlantis in Scotland, but in the opposite direction, and formed the southern boundary of the geosyncline; the western continuation of this zone can not be recognized in England possibly because of its burial beneath younger rocks, and possibly also because of the obliteration of this Caledonian element by the succeeding Armorican orogeny which was not effective so far north as Scandinavia.

The Caledonian orogeny, therefore, affected a northeast-southwest zone which covered all Scotland and most of Wales and northern England, and within this belt posthumous folding along Caledonian lines has occurred later in geological time in accordance with the principle that lines of crustal weakness persist as such through long periods of time, and may always be the focus for renewal of movement.

ARMORICAN OROGENY

This is sometimes known as the Hercynian, or Variscan orogeny, and occurred from late Carboniferous time onward, culminating in the early Permian. In general the United Kingdom, however, did not lie in the main zone of movement as the northern limit trended east-southeast from the southern tip of Wales across southern England and into northern France, so that only a minor part of the country was subjected to intense deformation and the greater part of it constituted the rigid foreland which had been compacted by preceding movements. The reaction of this foreland to the impact of the Armorican forces farther south was to allow local movement along pre-existing basement trends of either Charnian or Caledonian age depending on which was dominant in any particular locality, and there is no trace in central and northern England of the true Armorican east-west trend of folding. From the previous discussion of the earlier orogenies the disposition of these folds and faults in the Armorican foreland will be clear, and a particularly interesting example is seen in the Pennine uplift of central England which displays an apparently incongruous north-south trend belonging to no known orogeny. Study of this major tectonic feature shows that from its southern end diverge a series of folds along Caledonian and modified Charnian trends and that northward these converge and disappear into the main rather narrow north-south Pennine ridge which is clearly seen to be a structure resulting from the intersection and interaction of the two basement trends present in the foreland. These posthumous structures are relatively gentle, and although some are steep and vertical dips are encountered yet over-folding and thrusting is absent. On the other hand, in the southern region of England which lay within the zone of the Armorican movements the folding shows the ordinary intensity associated with geosynclinal buckling with folding along the characteristic trend slightly south of east.

The line separating the zone of true Armorican folding from the foreland on the north has been termed by Stille the boundary between Meso and Paleo Europe.

ALPINE OROGENY

After the Armorican movements there was no further great orogeny until mid-Tertiary time. There is evidence admittedly of uplift and folding in late Jurassic, and early Cretaceous time in parts of the country which can be related to the Saxonian movements of the European mainland, but these in general did not partake of the catastrophic character of the movements already described and can not be classed as major features. Later, in pre-Eocene time there was wide-

spread uplift which led to considerable erosion of the Upper Cretaceous prior to the deposition of the Eocene; some folding did take place, notably an initial uplift of the Wealden anticline of southern England but in general this movement was epeirogenic and folding was conspicuous by its absence.

Since Paleozoic time the United Kingdom had been located in a zone of crustal rigidity north of the great geosynclinal sea of Tethys of which the present Mediterranean forms a much reduced remnant. The Alpine orogeny which culminated during the Miocene represents the buckling of the Tethys trough and the thrusting northward of the great mass of sediments which had been deposited therein from the Trias onward. These islands lay entirely outside the zone of deformation which was far to the south (compare position in preceding orogenies) and now the whole country can be said to be part of the Alpine foreland affected by only the weakened and almost spent crustal forces. The extent of these can not now be judged as Cretaceous and post-Cretaceous rocks are only preserved in eastern and southern England, and here the movement expressed itself by the development of large uplifts and downfolds with associated minor structures, that is, the Wealden uplift and the London and Hampshire basins. Only in the extreme south was anything approaching intense folding seen and this is restricted to the coastal strip of Dorset and the Isle of Wight where an anticline with a vertical north limb accompanied by small-scale thrusting is developed. The general trend of the Alpine folds in southern England is east and west and there is some reason to consider them as rejuvenated Armorican structures present in the Carboniferous basement, although certain authorities believe that this east-west trend is unconnected with earlier folding and is determined only by the disposition of the shallow Paleozoic basement in central England, which has acted as a buffer to movement in the south. It is of interest, however, in this direction that two test holes in this region located on post-Cretaceous folds penetrated the basement at horizons low in the Lower Carboniferous, suggesting that there was a zone of Carboniferous uplift in close proximity to, if not actually underlying, the surface fold, an occurrence which is probably more than coincidence, and which is at least suggestive of posthumous folding along earlier trends.

This brief review of the orogenic processes which have been operative shows that the Lower Paleozoic rocks over most of the country, and the Devonian and Carboniferous beds south of the Armorican fold boundary are too strongly disturbed and metamorphosed to hold out any prospects of oil production. This conclusion is useful in setting a lower stratigraphic limit, or basement level, in certain regions below which it is of little value to drill. Thus in southern England this basement may be taken as the base of the Mesozoic, while similarly in central and northern England, and south Wales it can be taken at the pre-Carboniferous surface.

Detailed Geological Structure of United Kingdom

In the preceding section the tectonic forces which have moulded the framework of the United Kingdom were briefly reviewed, and, with this information as

FIG. 9.—Structural units of United Kingdom. (1 inch equals 75 miles)

a basis, it is now intended to consider in detail the various structural elements which now make up the geological pattern of this country.

Reference to Figure 3 shows that, as might be expected from the geological history, there is every formation represented from pre-Cambrian to Pliocene with the exception of the Miocene. Furthermore, there is striking variation in the age and direction of adjacent folds which may have been initially produced by any of the four orogenic movements. The land area of the United Kingdom is only one half to one third of that of the state of Texas, so that the encyclopedic character of the geological record of this country may be appreciated.

Geologically, the United Kingdom consists of either outcropping, or only shallow, Paleozoic rocks with a comparatively thin skin of Mesozoic and Tertiary sediments occurring in eastern and southern England. A few deeply downwarped regions with a locally thick section of younger rocks do occur between rigid blocks of compacted ancient sediments which have been permanent masses from Permian time onward. The Jurassic and Cretaceous sediments have now been stripped back by erosion to the east a long way from their original westward limits which probably extended as far as northern Ireland and western Scotland. The conception, therefore, of numerous Paleozoic massifs with locally restricted areas of thick sedimentation between them is one which gives the best picture of the United Kingdom. The various structural elements of the country are depicted in Figure 9 and the main points of each are here briefly summarized, commencing in the north and proceeding southward.

Scottish Highlands.—This region consists of highly overfolded and thrust Archean crystalline schists and gneisses which, as already stated, form part of the northern belt of Caledonian folding. Some Cambrian sediments occur, and on the east coast there is a fringe of Devonian and Jurassic rocks. The southern boundary of this unit is the Highland Boundary fault, a great northeast fracture which downthrows the Devonian of the Midland Valley against the pre-Cambrian of the Highlands.

Midland Valley.—This is a great trough, or rift, let down between the Highland Boundary fault on the north, and the Southern Boundary fault on the south, in which Devonian and Carboniferous rocks are disposed regionally in synclinal form at the surface. The Lower Carboniferous is the thickest division, and shows up to 7,500 feet of beds of which the lower 4,000–5,000 are predominantly estuarine and fresh-water, the upper portion being more marine in character. Intense igneous activity took place throughout the Lower Carboniferous, thick masses of lavas were extruded periodically, and deep-seated masses of igneous rock were intruded at depth.

Closed structures occur in the eastern end of the Valley in outcropping Lower Carboniferous beds, but westward in the deepest part of the Valley, occupied by Coal Measures at the surface, the two factors of igneous activity and widespread faulting tend to obscure the structural picture and although anticlinal folding is present it is complicated and simple closures are not represented. At the western

end much of the Lower Carboniferous is replaced by contemporary lavas and rapid changes in thickness take place that can not be predicted in detail.

Southern Uplands.—This region is essentially an anticlinorium, formed by the Caledonian orogeny, the axis of which lies near the northern edge formed by the Southern Boundary fault. The surface beds are Lower Paleozoic, and intense isoclinal folding is a feature of the area which stands up as a barren moorland and has probably been a land area from Permian time onward.

Bewcastle Fells.—Southward from the Southern Uplands comes that region of northern England known as the Bewcastle Fells, which includes the Cheviot Hills, the remains of a deeply eroded volcano of Lower Devonian age now evidenced by a great mass of granite which forms part of an original laccolite.

The Bewcastle Fells are occupied almost entirely by outcropping Lower Carboniferous sediments which exhibit the typical deltaic Northumbrian succession, with thick sandstones and coals forming a characteristic type of the lower, and thicker, part of the section. Regionally, the structure is a general dip slope toward the southeast off the Southern Uplands swinging east round the Cheviot mass. Rolling occurs and gives rise to a very low dome, the Bewcastle arch, which cuts down into the basal Carboniferous, while on the coast appears the western limb of a north-south syncline in Upper Carboniferous which forms the northern part of the Durham coal field. The southern limit of the Bewcastle Fells is abrupt and formed by the east-west Stublick fault which is itself the northern edge of the Yorkshire-Durham massif. In the vicinity of this fault there is more intense and sharper local folding accompanied by a rapid thinning and disappearance against the massif of 6,000 feet of beds, comprising in ascending order the Cementstones, Fell sandstone, and part of the Scremerston Coal group. Only the more marine upper portion of the Carboniferous, exhibiting the typical shallow-water Yoredale facies, is continuous from the Bewcastle area over to the Durham massif. The total thickness of Lower Carboniferous present in this region is 8,000 feet. No oil or gas showings are known.

Carlisle basin.—Southwest of the Bewcastle Fells lies the Carlisle basin, a Trias filled depression probably initiated in post-Carboniferous time, and accentuated later in the Tertiary.

Little is known of its sedimentary fill but study of the surrounding sediments suggests that, including Carboniferous rocks, this may average 8,000 to 9,000 feet with a maximum of 12,000 feet. The estimated average thickness for the present components of this fill is as follows.

	Feet
Jurassic	100
Triassic	1,500
Permian	500
Upper Carboniferous	1,700
Lower Carboniferous	4,700

Interest from the oil point of view lies only in the Lower Carboniferous which shows a more marine facies than that occurring in the Bewcastle Fells on the immediate east.

Over much of the region surrounding the Carlisle basin is a large-scale intra-Millstone grit unconformity which cuts out much of this formation, and is presumed to continue within the basin at depth. In addition, a major unconformity separates the Trias and Permian from the Carboniferous, any Armorican structures at depth are not reflected at the surface and may have suffered considerable pre-Permian erosion.

Gravity work over the basin has been used to make some hypothetical reconstruction of the Lower Carboniferous structure by integration of Δg profiles and the results, although entirely theoretical, probably give a clue to possible folding; one anticlinal line is indicated by this work with no closure however, other than that provided by faulting.

Apart from Coal Measure seeps of oil, whose doubtful value has already been discussed, this feature is devoid of any showings of oil or gas.

Durham-Yorkshire massif.—This is an uplifted fault block of Lower Paleozoic sediments which formed part of the old Devonian continent, and stood up as an unsubmerged massif through much of Lower Carboniferous time with a controlling influence on local sedimentation.

This massif is actually composed of two units, a northern one termed the Alston block centering over Durham, and a southern one, the Ingleborough block in Yorkshire, separated by an intervening saddle. It is bounded on the north, west and south by large faults and there is in general a low eastward dip of the pre-Carboniferous floor which is exposed by erosion at several points and has been reached at the shallow depth of 2,100 feet in a boring on the eastern side of the massif. The eastern limit is not known but a strong north-south-trending fault off the Yorkshire coast has been suggested as being the boundary in this direction.

The sedimentary cover over the massif is very thin, being only 1,800 feet at maximum of Lower Carboniferous with a thin Millstone grit section coming in on the eastern side. There is a regional dip toward the east with locally two very low gentle arches over each of the two component units of this element. The Lower Carboniferous is developed in the specialized massif facies of shallow-water Yoredale-type sediments.

Lake District dome.—This structural feature consists of a large complex strongly folded dome of exposed Lower Paleozoic rocks fringed on the edges by Carboniferous and Trias sediments. This uplift is primarily a product of the Caledonian orogeny, which was accompanied by the deep-seated intrusion of igneous material, and further movement took place though to a smaller degree in post-Carboniferous and Tertiary time.

The Lake district actually forms a western extension of the Yorkshire massif, and in Lower Carboniferous time these two were part of the same Paleozoic ridge; there is now faulted contact between these two features on the south-eastern side of the dome while to the east and north they are separated by the Eden Valley, a small rift filled with Permian sediments.

Yorkshire basin.—This is a depositional basin of Jurassic age which was a sagging area throughout the period and received 3,000 feet of Jurassic sediments.

Folding ensued in post-Jurassic and Tertiary time which accentuated the basin form and gave rise to several well marked subsidiary structures, chief of which is the Cleveland arch, an east-west-trending gentle anticline, of at least 1,000 feet relief on either flank, plunging east. Superimposed on this arch are several local closures whose northwest trend suggest Charnian influence. Between the dying-out of the Cleveland fold and the sea coast are two separate north-northwest-trending closed anticlines, one of which has been partially breached by the sea.

Taking the pre-Carboniferous surface as the local basement there is here a wedge of Permian, Trias, and Jurassic sediments, which thicken from an estimated 2,500 feet at the western edge to 8,000 feet on the coast, with comparable thinning both north and south from the central axis. The present basin is still quite open toward the east on the coast and shows no sign of shallowing in that direction, so that it is clear that the larger part of this depression lies out beneath the North Sea. The maximum estimated thickness for the various members of the sedimentary fill is as follows.

	Feet
Jurassic	3,000
Trias	3,000
Permian	1,500
(Carboniferous+2,500 feet) known from drilling	

which gives a depth to the local basement of at least 10,000 feet at the deepest part of the basin preserved as land. The surface rocks over most of the basin are Jurassic, and on the crest of the Cleveland arch the lowest beds of this age have been exposed.

The Trias sediments consist of continental redbeds with an upper marl section and a lower sandstone section, while the Permian shows an alternation of dolomitic limestones and marl-evaporite section.

The Yorkshire basin overlies directly the eastern continuation of the southern unit of the Durham-Yorkshire massif, and it has been suggested that after receiving an initial tilt toward the east in post-Carboniferous time this block continued to pivot and be depressed by the ever increasing load of Jurassic sediment. The Permian limestone, mentioned already as a possible producing formation, lies under cover of varying thickness throughout the Yorkshire basin. Gas showings in the Upper Permian evaporites are common in borings on the edge of the basin and slight showings of oil have been noted in the Jurassic. It is believed that the Cleveland anticline may be the result of posthumous folding of older Carboniferous trends, though this point is still open to discussion.

Craven Lowlands.—This unit comprises a region of outcropping Lower Carboniferous and Millstone grit sediments which has been folded into a series of steeply dipping high-relief northeast-southwest anticlines of Caledonian trend. Erosion has exposed low horizons of the Lower Carboniferous in the core of the majority of these folds. The stratigraphy of the Craven section has already been described earlier in this paper and it may be recalled that the normal limestone facies of the Lower Carboniferous is here represented by an alternation of dark

shales and limestones. Evidence of contemporaneous erosion and uplift is indicated at certain levels in this area.

Pennine uplift.—This great uplift has been called the back-bone of England, and this term is apt, not only geologically, but also topographically as it forms a continuous ridge of high moorland country between 1,000 feet and 2,000 feet high extending 50 to 60 miles. The term Pennine uplift is restricted here to the high ridge trending southward from the Craven Lowlands to the Staffordshire basin though the term is applied by many authorities to include the Yorkshire massif as well. This, however, is such an entirely different structural type that it is considered it should be dealt with separately.

Geologically the Pennine uplift is an asymmetric anticline with a steep, in many places intensely faulted western limb and a gentle eastern flank. The structural relief of this major fold is many thousands of feet on either flank, that on the west being probably of the order 10,000 feet. Local closures, many of considerable size, occur along this axis which dies out northward against the Caledonian folding of the Craven country and southward passes into the Trias-filled Staffordshire basin. At the southern end, associated, though smaller, anticlines of Caledonian and modified Charnian trend occur. As has already been mentioned, the Pennine uplift is not a fold representative of any one direction of folding and although originally developed during the Armorican orogeny is not in any way typical of the trends of this movement. Rather is it the resultant structure derived from the mutual interaction of the two ancient sets of fold lines in the Armorican foreland. This uplift exposes various horizons of the Millstone grit along its course, those cropping out on the crests of the local "highs" occurring low in this formation which is increasing in thickness northward to a maximum of 6,000 feet.

Derbyshire dome.—Closely associated with the southern portion of the Pennine anticline and immediately east of it is the Derbyshire dome, a tectonic feature which structurally, however, is of a very different type and is really an entirely different tectonic element. It consists of a broad, relatively flat-topped dome which brings the Carboniferous limestone to the surface over an area of 200 square miles to form the mountainous and scenically beautiful Peak district of Derbyshire. The axis of the structure is northwest and southeast, a typical Charnian trend, which is aligned exactly with the pre-Cambrian axis of Charnwood Forest exposed some distance toward the southeast. There seems little doubt that the dome represents renewed movement along an extension of the Charnwood axis and it is possible that, like the Yorkshire massif, the ancient foundation of the present Derbyshire dome was unsubmerged until late in Lower Carboniferous times while it is fairly clear that it was again a landmass during the deposition of the basal Millstone grit sediments. The trend of this feature abutting directly against the strike of the Pennine anticline is most illuminating and illustrates the "unnatural" trend of this latter element compared with the fundamental orogenic direction of the dome and Charwood. The structural relief

of the dome is less than that of the Pennine uplift, on the eastern flank it is of the order of 5,000 feet and on the west it is rather less, probably 2,000 to 3,000 feet. The Lower Carboniferous is exposed to a stratigraphical depth of 1,600 feet on the crest of the dome.

The Derbyshire dome and the Pennine anticline can be described as together forming the southern portion of the Pennine uplift whose gentle eastern flank is seen from surface exposures and colliery workings to be folded into a series of anticlines whose trend varied north-northwest to west-northwest, obviously modifications of the Charnian trend. These folds are well defined structures with relief ranging from 1,000 to 3,000 feet and with local closures developed at intervals along their crests. An interesting structural feature is the occurrence of strong normal faulting on the south flank of many of these structures parallel with the axis.

North of the Derbyshire dome the eastern flank of the Pennine uplift, here coincident with the Pennine anticline, shows an absence of these anticlinal folds and relief of earth stresses has been achieved by large-scale faulting along two intersecting trends rather than by normal compressional folding.

Cheshire and Lancashire basins.—These features may be taken regionally to represent the western flank of the Pennine uplift and its northern extension into Yorkshire, the Carboniferous beds of the uplift being deeply buried beneath a thick mantle of uncomformable Permian and Trias sediments. The two basins are partially separated by a Carboniferous horst structure, the Rossendale uplift trending east-northeast, but they are continuous in the Trias round this uplift in the vicinity of Liverpool.

The Lancashire basin is breached by the sea and actually only the eastern portion is now preserved on land. Its eastern boundary is essentially faulted, with the Trias-filled basin downthrown against the outcropping Carboniferous beds of the Craven Lowlands.

Within this feature occurs the group of active oil seeps centering round the town of Formby, and this superficially attractive indication of oil accumulation has led to considerable geophysical prospecting to investigate the possibility of deeply buried Carboniferous structures beneath the Trias. Conclusions drawn from the study of both gravity and seismic work suggest that the Caledonian trends of the Craven Lowlands may continue southwestward into the Lancashire basin, and one such Carboniferous fold can be traced at the surface right up to the faulted eastern boundary of the basin.

Test drilling has shown that a section of Permian and Trias redbeds, mainly arenaceous, are present up to a thickness of 6,000 feet and this great section may have been partially accommodated by the westward sagging of the basin along normal faults contemporaneous with deposition of the Permian.

The Cheshire basin has been shown by gravity work to be essentially a rift bounded by two great faults, or fault zones of Caledonian trend, and this region has been in downward movement over long periods of time during which it has

accommodated a vast thickness of sediment. It is estimated that in the center of the basin the following section is present.

	Feet
Trias	5,000– 6,000
Permian	?
Carboniferous	8,000–10,000

Accordingly the pre-Carboniferous floor may be at depths of 13,000 to 15,000 feet below sea-level. A feature of this section is that up to 75 per cent of it consists of non-marine deposits as, in addition to the continental Trias redbeds, there is a maximum development in the Cheshire basin of the non-marine Upper Coal Measures which were laid down under lagoonal conditions on an emerging land area. Furthermore, the Millstone grit and the Lower Carboniferous of this section present rather different stratigraphical aspects from the normal Midland development, suggesting local near-shore deposition in partially enclosed shallow seas.

The Cheshire basin is separated from the Pennine uplift by a boundary fault of several thousand feet downthrow on the west, and large-scale normal faulting is a marked structural feature of this depression both within and round the margins. Carboniferous structures related to the Pennine uplift may be present at great depth, but the degree of pre-Permian erosion to which they may have been exposed is unpredictable while faulting has probably cut such folds into a series of blocks. No oil showings are known within the basin, but on the southern and western margins there are small showings of oil, commonly dark and heavy, in colliery workings, which are not considered, however, to be of much significance and do not indicate large-scale accumulations within the basin. The Lancashire and Cheshire basins, although initially folded in post-Carboniferous time, have suffered further deformation after the Jurassic period, as a small Jurassic outlier showing synclinal form occurs in Cheshire, and in all probability this later folding was accomplished during the Tertiary.

The East Midland Mesozoic monocline.—This structural unit comprises two separate layers of geology above the pre-Carboniferous basement, an eastward-dipping, unfolded Mesozoic section overlying, with great unconformity, folded Carboniferous rocks which are the continuation of the eastern flank of the Pennine uplift.

The upper layer of low-dipping Permian to Cretaceous rocks present no particular structural interest as, apart from a slight eastward tilt in Tertiary time, no tectonic movements of any magnitude have affected these sediments. No overlapping of lower by higher beds is seen in the present state of erosion except towards the extreme north where the Cretaceous oversteps all the Jurassic members in turn. The maximum thickness in rocks involved in this eastern dipping series is as follows.

	Feet
Cretaceous	+ 500
Jurassic	±2,000
Trias	±2,100
Permian	+1,000

These figures are compiled from the various points of the area in question as no deep hole has ever been drilled in a location right down the regional dip.

The Permian unconformity at the base of this geological layer has an extremely regular dip of 100 feet per mile, implying virtual peneplanation of the folded Carboniferous prior to Permian deposition. The underlying layer of rocks consisting of folded Carboniferous beds is, of course, completely buried and its disposition was originally only known from the workings of some easterly advancing collieries and a few scattered boreholes. These suffice to show at least that the folded condition of the exposed eastern flank of the Pennines continue beneath the Mesozoic cover, and subsequent geophysical work, to be mentioned later, has considerably amplified the Carboniferous picture and revealed the presence of a number of high-relief post-Carboniferous folds.

Staffordshire basin.—This is a little known depression lying south of the Pennine-Derbyshire dome uplift against the edge of the rising platform of old Paleozoic rocks of the Midlands. No holes have been drilled into it to any great depth but at least 2,000 feet of Triassic beds are known to be present in the deepest part. The deposition of Carboniferous rocks is irregular within this basin as they are here wedging out against the Paleozoic ridge at the south with its rugged subsurface relief, and lying thus against the basin edge these sediments have been subject to intermittent and local uplift, or depression, which has removed or accentuated parts of the succession with relation to adjacent portions. Thus in one exploratory borehole for coal the section showed Trias resting on Lower Carboniferous, while elsewhere, however, similar bores have found Upper Carboniferous to be present below the Trias.

Carboniferous structure beneath the Trias is little known, faulting is undoubtedly present on a large scale and the basin is probably cut into a series of fault blocks which have undergone independent movement. A fault-bounded ridge crosses the basin and separates a deeper western portion from an eastern shallow portion. Oil showings include the slightly impregnated Triassic sandstones near Burton and the heavy oil showings in the Upper Coal Measures of Coalbrookdale.

Midland barrier—East Anglian platform.—These two structural elements are together part of the relatively shallow basement of Lower Paleozoic rocks which underlies much of central and eastern England and which at various scattered points in the Midlands protrudes through the cover of Upper Paleozoic and Trias rocks. This is a remnant of the old Devonian continent and in Lower Carboniferous time formed the Midland barrier which divided the area of deposition into a northern and a southern basin, and which in Permian time was re-elevated to form the Mercian Highlands. In the succeeding Jurassic and Cretaceous period this feature has been repeatedly elevated and depressed but the East Anglian portion has persisted as an elevated landmass during much of Mesozoic time when the Midland portion was submerged. Jurassic and Lower Cretaceous sediment wedge out against the East Anglian platform from south-

west and northwest and it was not until Upper Cretaceous time that it finally submerged. Elimination of the effects of Alpine folding and tilting defines the Mesozoic disposition of this landmass clearly, and the gradual advance of Jurassic and Lower Cretaceous sediments on it from all sides can be followed by means of the excellent subsurface control which is available. North of an east-west line through London there is a big area in Essex and Suffolk where Upper Cretaceous sediments of Albian age rest directly on the Lower Paleozoic rocks of the old landmass, thus defining the extent of the existing land area prior to the Cenomanian transgression.

The Alpine orogeny has modified the disposition of the old surface depressing it on the southeast and elevating it on the west so that actually the old East Anglian platform now extends for considerable distance west of its original limits and outside the true geographical region indicated by the title; it is, however, all part of the same geological unit and the term is not inaccurate to describe it. Figure 10 shows the general relief on the pre-Carboniferous surface in the light of our present knowledge, and indicates that the old rocks lie in general at less than 2,000 feet subsea over a large region in central and eastern England. The Midland barrier is now covered by a greatly varying thickness of Upper Carboniferous and/or Triassic rocks, while eastward to East Anglia the cover over the platform is Triassic, Jurassic, and finally Cretaceous in turn as these formations wedge out toward the east.

London basin.—The London basin is a broad complex syncline rising toward the north, south, and west in Upper Cretaceous and Tertiary beds whose age of main folding is definitely post-Eocene, and can, therefore, be ascribed to the Alpine movements of the Miocene. The northern flank overlies a thin south-wedging section of Jurassic and Lower Cretaceous beneath the Upper Cretaceous compared with a thicker section of these beds on the southern flank, while in the middle of the basin the Upper Cretaceous lies directly on the Paleozoic platform which is falling steadily from north to south beneath this depression.

Minor wrinkling occurs within the syncline, principally on the southern edge and westward extension where a greater sedimentary cover is present above the rigid basement. The thickness of Tertiary and Cretaceous beds in the vicinity of London average 1,000 to 1,200 feet near the center of the basin at its eastern end while at the western end there is a great increase in section owing to the coming-in of the Jurassic and Trias so that probably there is at least 7,500 feet of sediments above the Carboniferous.

The London basin is a structural unit presenting a peculiar aspect in that it is developed partially in a thick section of Mesozoic and Tertiary rocks, and partially in a very thin section of similar beds overlying a shallow rigid basement.

Wealden uplift.—This structural element is a complex anticlinorium developed over a thick section of Mesozoic rocks which comprises the whole of southeastern England. It may be considered as a complementary uplift to the London basin, and grew structurally from late Cretaceous time onward to the Miocene.

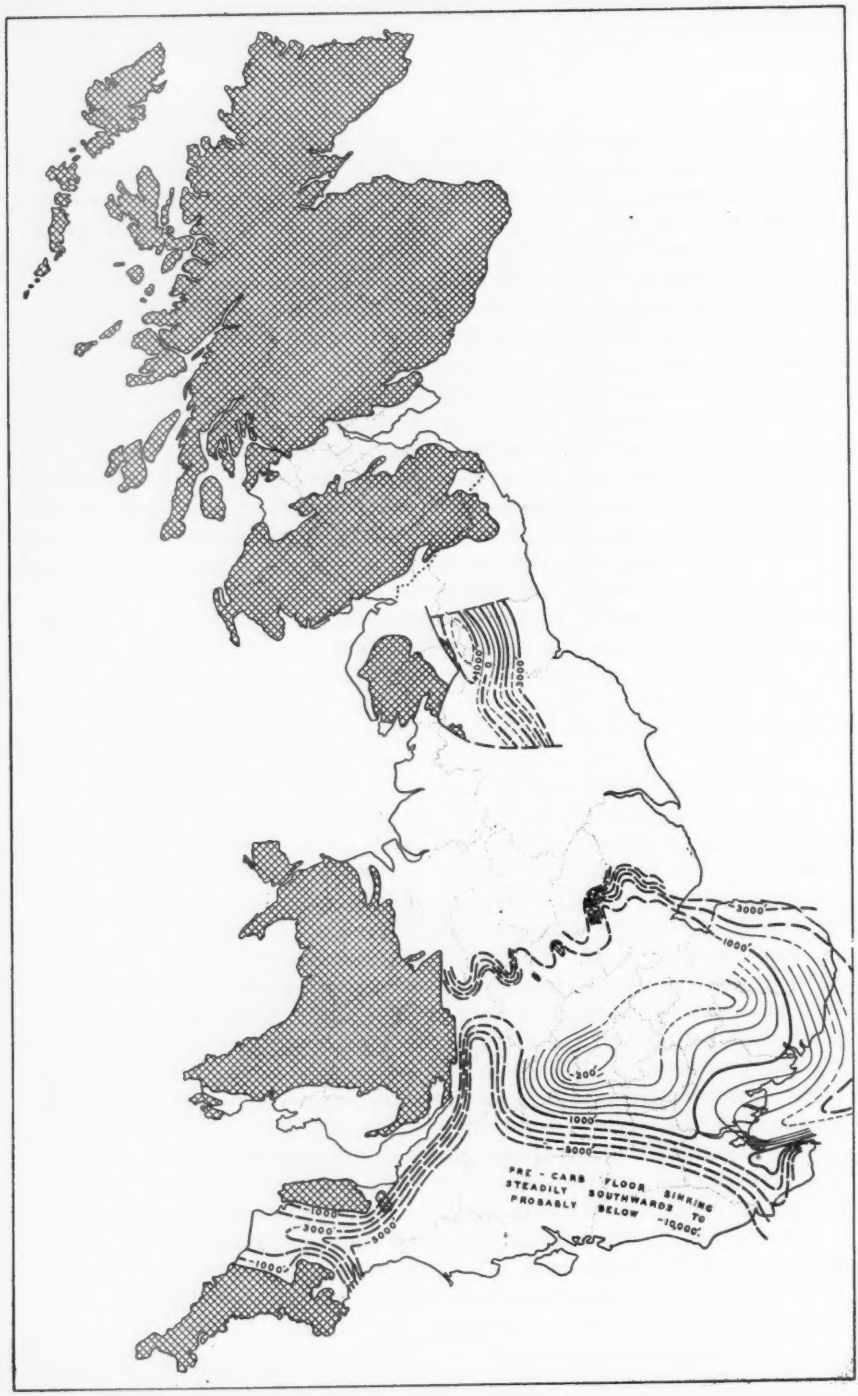


FIG. 10.—Generalized contour map of pre-Carboniferous basement.
(1 inch equals 75 miles)

The uplift is preserved in southeastern England as part of a true dome, with a marked western plunge while eastward the complete periclinal form is broken by the sea and the continuation of this structure must be looked for on the northeast coast of France. Topographically, the Weald is clearly expressed as a central flat area formed of Lower Cretaceous sands and clays which are enclosed by encircling scarps of Upper Cretaceous chalk which give rise to the high country of the "Downs" of southern England.

The major axis of the uplift is not continuous, but comprises two separate axes *en échelon* with one another, the easterly one exposing Upper Jurassic beds in a series of faulted inliers, while the westerly one is eroded down to the basal Lower Cretaceous. Over-all relief of the uplift from the south flank, down to the bottom of the Hampshire basin, is of the order 6,000 feet to 7,000 feet, while on the northern limb the rapid thinning toward the Paleozoic platform under London causes the relief to be very much less.

Impressed on the flanks of the main uplift are a number of subsidiary folds of varying amplitude and size, those on the southern flank falling into three belts within which the individual structures occur *en échelon*. The closures of these subsidiary folds range from 100 feet to 200 feet for those near the crest of the uplift, increasing to 500 feet or 1,000 feet for folds farther down the southern flank.

The area south of the Paleozoic platform under London now occupied by the Wealden uplift was throughout Jurassic and Cretaceous time one of continual and large-scale downwarping in which a thick section of the sediments of these two systems accumulated. There is a component of thickening both on the west and south, with the direction of the greatest thickening toward the southwest away from the Paleozoic landmass which swings round from London in a southeast direction across Kent and thence on to Belgium. In Kent the total Mesozoic section at Dover is only 1,158 feet, with much of the Upper Jurassic missing, and of which 516 feet comprises Cretaceous beds, while in the western part of the Weald the same Mesozoic section is of the order 6,000 to 7,000 feet, each member being expanded progressively toward the southwest.

Locally there are impressive oil and gas shows in the Lower Cretaceous and Upper Jurassic which have already been described. It is noteworthy that these are not widespread and occur only at isolated points.

Hampshire basin.—This is a deep basin which is the complementary downwarp to the Wealden uplift. Structurally it is a complete basin, being bounded on the south by a steep-flanked anticline through the Isle of Wight, and with gentle dips on the mainland in toward the center which is located on the northern portion of that island. It is probable that the original depositional basin extended farther south, of which the present feature is a structurally defined portion.

The Hampshire basin occurs in what is probably the deepest portion of the Mesozoic trough of southern England, and downwarping must have continued well into Tertiary time as not only is a thick Eocene section present, but also a representative development of the Oligocene. It is thus a direct reflection of the

steady sagging of the basement which must have proceeded from pre-Jurassic time onward.

Structurally, the Hampshire basin is uncomplicated by associated folding and regular dip slopes, with no minor wrinkling to speak of, are a characteristic feature of it. The section present in the deepest part is estimated to be as follows.

	Feet
Oligocene	± 500
Eocene	±1,300
Cretaceous	±3,400
Jurassic	±4,000
Trias and Permian . . . Present, but no estimate possible	
	+9,200

Carboniferous rocks are probably present below the Trias and Permian so that the old pre-Carboniferous floor must be depressed here to possibly as deep as 15,000 feet subsea while the Carboniferous would not be encountered above 10,000 feet subsea.

No showings of oil or gas are known within the basin proper. The Lower Cretaceous and Jurassic showings of the Dorset coast already described lie on the southwestern edge and may be related less to the present structural basin than to a continuation of the same feature lying beneath the English Channel.

The Hampshire basin passes northward into a region of gently rolling Upper Cretaceous uplands, which lie west of the Wealden uplift. Several east-west-trending anticlines traverse this region, but they are of no great amplitude and plunge toward the west with no development of local closures along their axes. Some of these folds are aligned with, and represent the continuation of, several of the Wealden anticlinal lines.

Cornubian massif.—The western limb of the Hampshire basin rises gradually westward and successively older beds crop out in this direction toward the Paleozoic mass of Cornwall, with parts of Devon and Somerset, which formed the western landmass to the Mesozoic trough. The massif is in the main a great synclinorium of Paleozoic rocks with a core of Carboniferous which is flanked by Devonian rocks on the north and south, a structural development of the Armorican orogeny. The sediments comprising the massif have been intensely folded, overthrust, and faulted while widespread metamorphism has been effected by the intrusion of granite masses, contemporaneous with folding, which are now exposed at the surface to form the topographic features of Dartmoor, Exmoor, *et cetera.*

Welsh Paleozoic massif.—This is a mountainous region of strongly folded Lower Paleozoic rocks, uplifted and compacted by the Caledonian orogeny, and since that time a permanent massif which has persisted as land until the present day except during Upper Cretaceous time when its possible submergence is a debatable point.

South Wales basin.—This tectonic depression is a product of the Armorican orogeny, now filled with Carboniferous rocks. It is a good example of a structural basin although at its western end it has been breached by the sea at several

points. It is an elongate narrow feature with a typical east-west trend and well defined dip slopes on the north, east, and south which causes the various members of the Carboniferous to swing round in a series of concentric curves. Depositionally it forms but a small part of the much larger southern region of Carboniferous sedimentation and therefore the thickest section occurs toward the southern limb of the basin. The maximum Carboniferous fill is estimated to be 12,000 feet of which the Coal Measures at their thickest development on the southern edge contribute up to 8,000 feet. From this maximum there is a progressive thinning of the Carboniferous section toward the eastern edge of the basin, formed by a pre-Carboniferous anticline, where it is represented by only 2,000 to 2,500 feet of sediment.

An erosion period occurred within the Lower Carboniferous which on the northern limb causes considerable unconformity and overlap of the older formations by younger. In the beginning of the Upper Carboniferous, uplift and initial folding of the basin occurred so that the Millstone grit rests with marked unconformity on various formations of the Lower Carboniferous at the edges of this depression. Two major anticlinal folds trend east and west in the center of the basin with closures of the order of 500 feet, while large north-northwest-trending fractures cutting right across are of common occurrence. Oil showings are entirely absent apart from the very restricted occurrence of greasy material in the Carboniferous limestone on the northern limb.

Selection of Prospective Petroliferous Areas

After consideration of the geological history and the likely oil-source formations, followed by a study of the geological structure of the United Kingdom, it is possible to select with some certainty those regions which possess prospects of being petroliferous, and at the same time eliminate those areas which for either structural or stratigraphic reasons, or both, hold no hopes which have any reasonable scientific basis.

It is believed that regions fulfilling the following geological conditions can be classed as potentially petroliferous in the order of importance given.

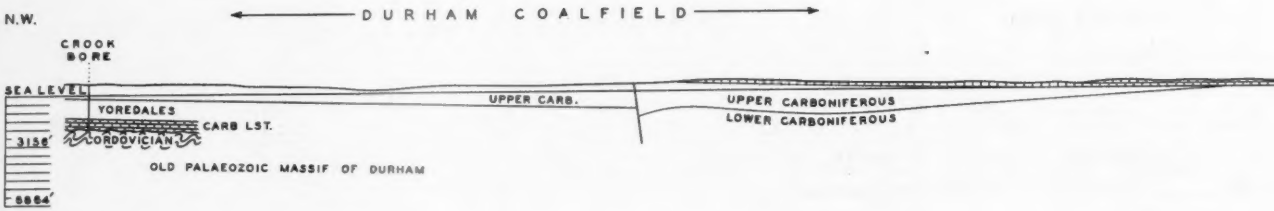
A. Regions where Carboniferous and Jurassic sediments are under adequate cover and have not been subjected to deep erosion immediately subsequent to deposition
B. Regions of outcropping Carboniferous and Jurassic sediments which have not suffered too deep erosion
C. Region where the Magnesian limestone facies of the Permian is under adequate cover
D. Region where the basal sands of the Lower Cretaceous Wealden beds are under adequate cover

No consideration of possible trapping conditions enters into this primary classification of prospects, which is concerned solely with the presence of suitable sedimentary sections. Where such sections are found to be present then the question of suitable traps, either structural, stratigraphical, or lithological, becomes the governing factor which decides the ultimate worth of any particular prospect and localizes those parts of it which merit test drilling. In the following

FIG. 11.—Map showing major post-Carboniferous anticlines not eroded below Upper Carboniferous. (1 inch equals 75 miles)

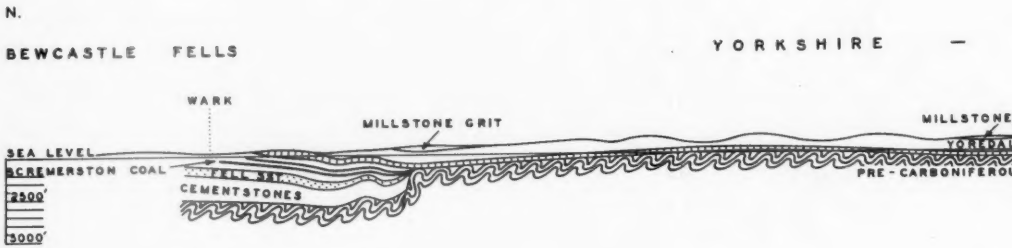
H. R. LOVELY, "GEOLOGICAL OCCURRENCE OF OIL IN UNITED KINGDOM," BULL. AMER. ASSOC. PETROL. GEOL., VOL. 30, NO. 9 (SEPTEMBER, 1946)

LINE A-B

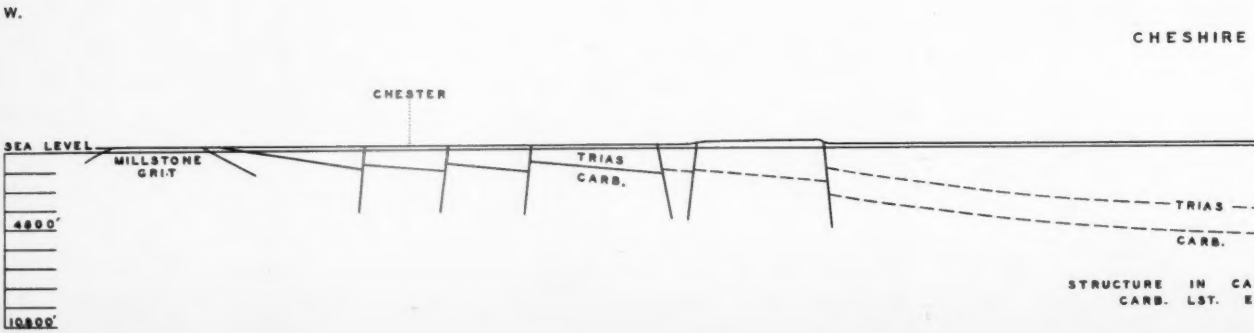


LINE C-D

SECTION THROUGH THE C



LINE E-F



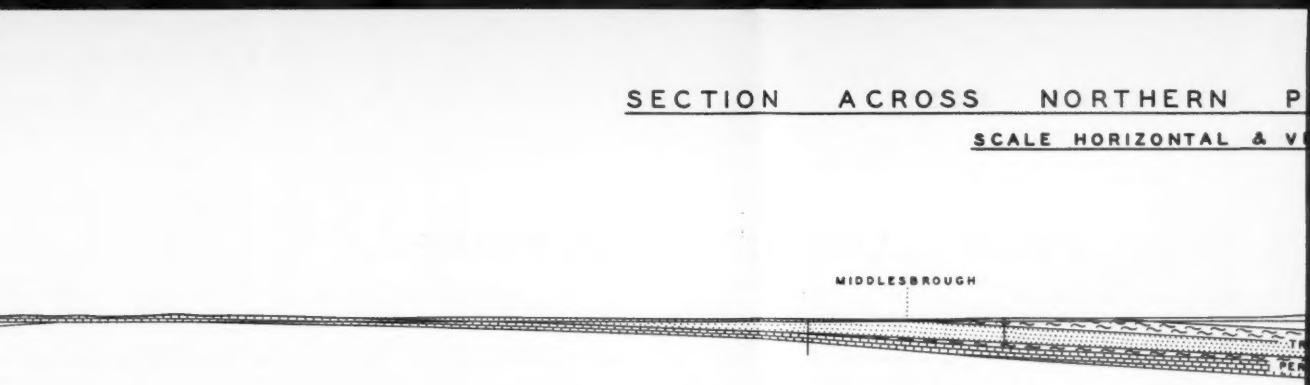


FIG. 12.—Section along line *AB*, shown in Figure 2. Scal

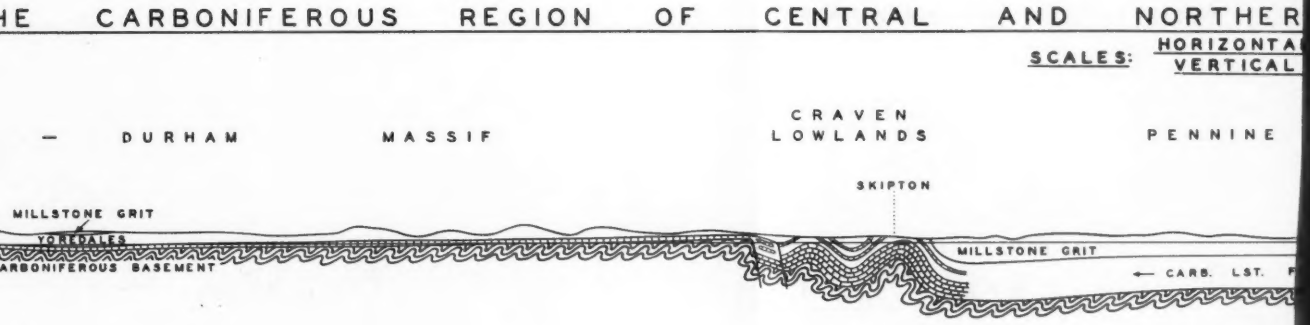


FIG. 13.—Section along line *CD*, shown in Figure 2. Scale: horizonta

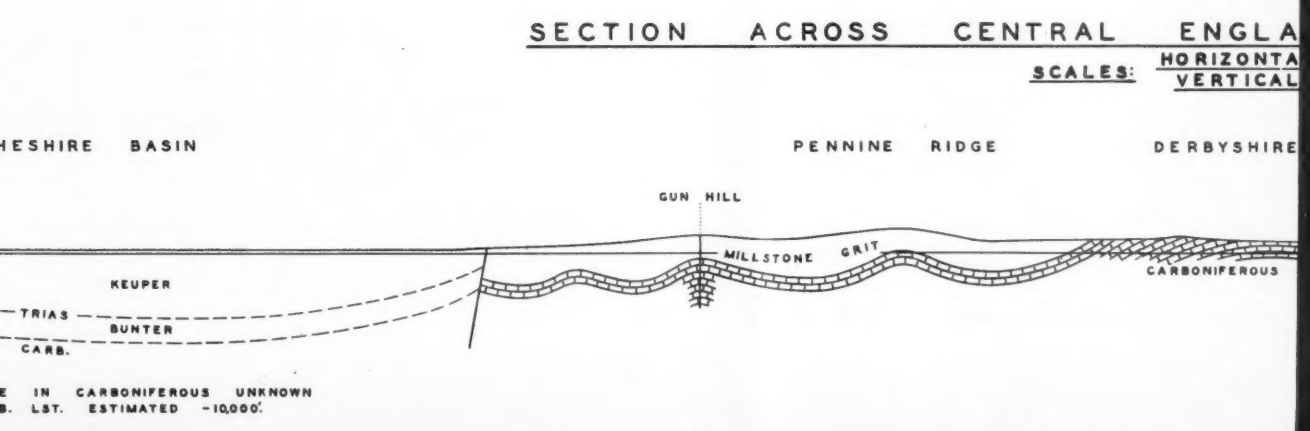
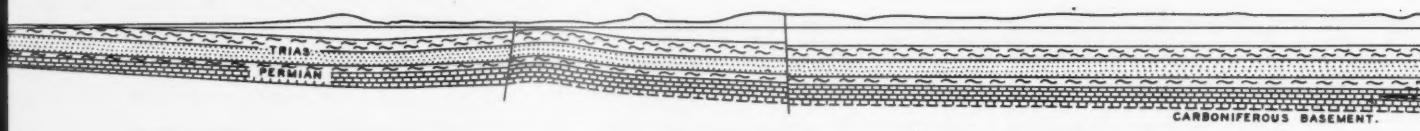


FIG. 14.—Section along line *EF*, shown in Figure 2. Scale: horizon

NORTHERN PART OF YORKSHIRE BASIN.

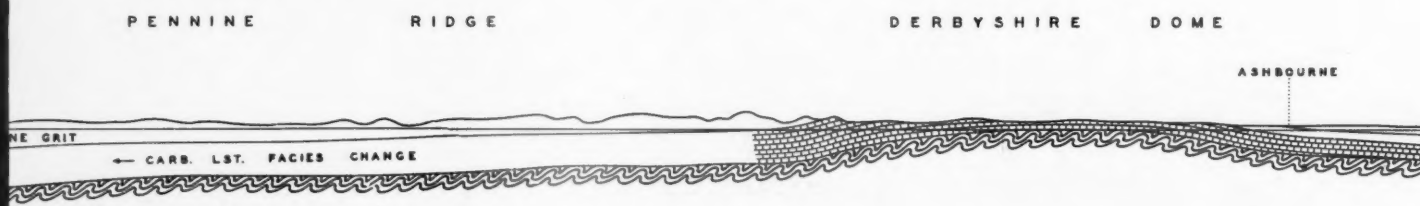
LE HORIZONTAL & VERTICAL ½=1 MILE.



g line *AB*, shown in Figure 2. Scale: horizontal and vertical, 1 inch equals 2 miles.

ND NORTHERN ENGLAND SHOWING FACIES CHANGES OF THE

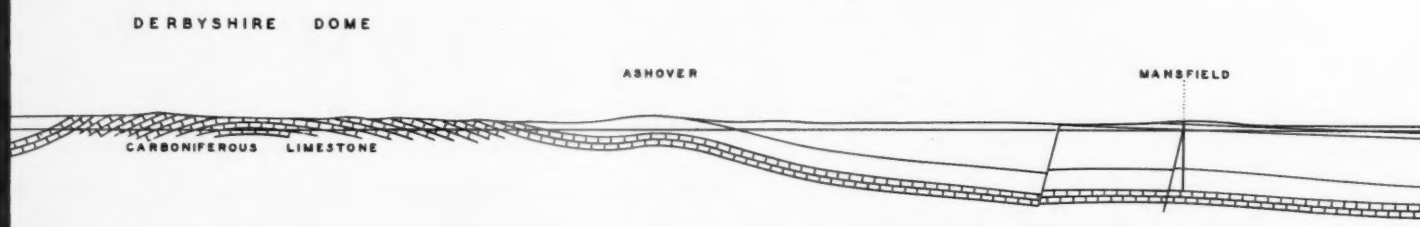
SCALES: HORIZONTAL 1"= 8 MILES.
VERTICAL 1"=10000 FEET



own in Figure 2. Scale: horizontal, 1 inch equals 8 miles; vertical, 1 inch equals 10,000 feet.

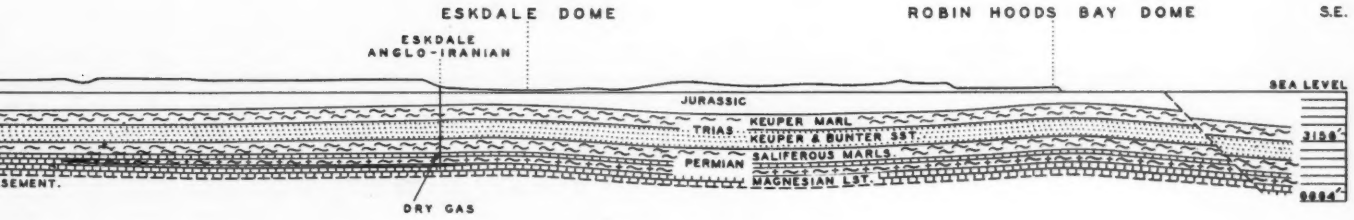
TRAL ENGLAND THROUGH PENNINE UPLIFT.

SCALES: HORIZONTAL 1"= 4 MILES.
VERTICAL 1"= 2 MILES.

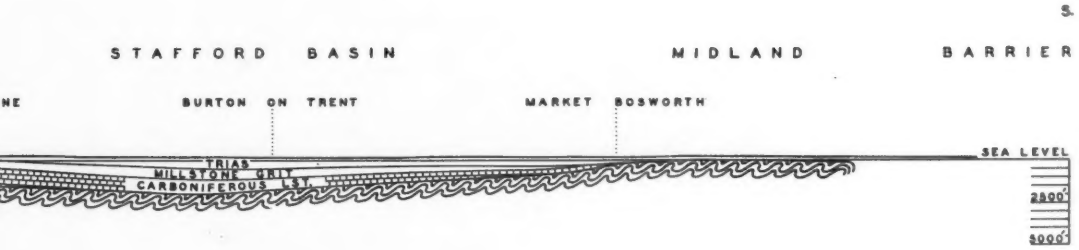


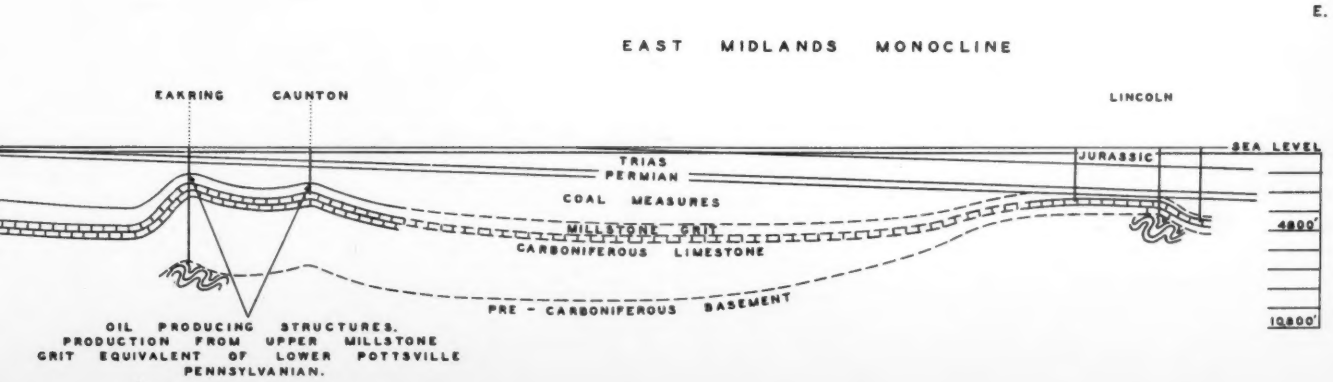
hown in Figure 2. Scale: horizontal, 1 inch equals 4 miles; vertical, 1 inch equals 2 miles.

PROD
GRIT



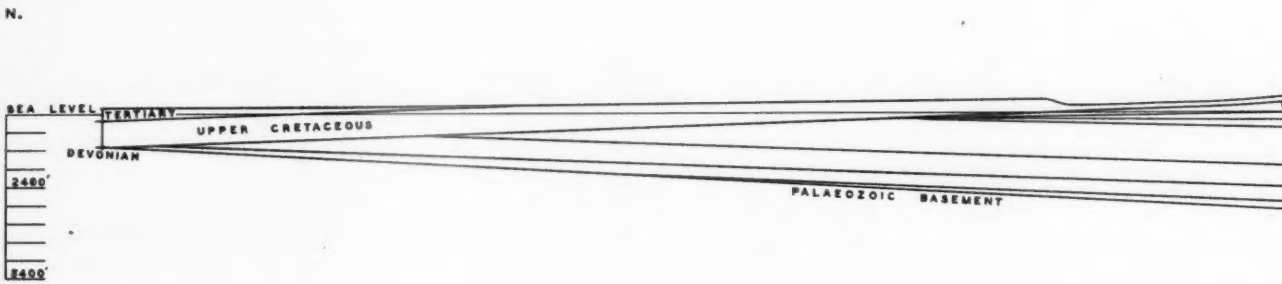
THE LOWER CARBONIFEROUS.





LINE G-H

LINE I-J



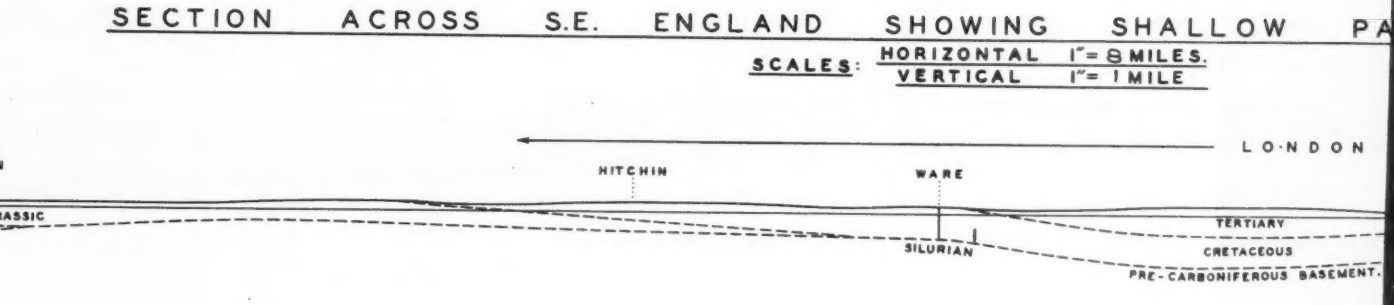


FIG. 15.—Section along line *GH*, shown in Figure 2. Scale: horizontal 1 inch equals 8 miles; vertical 1 inch equ

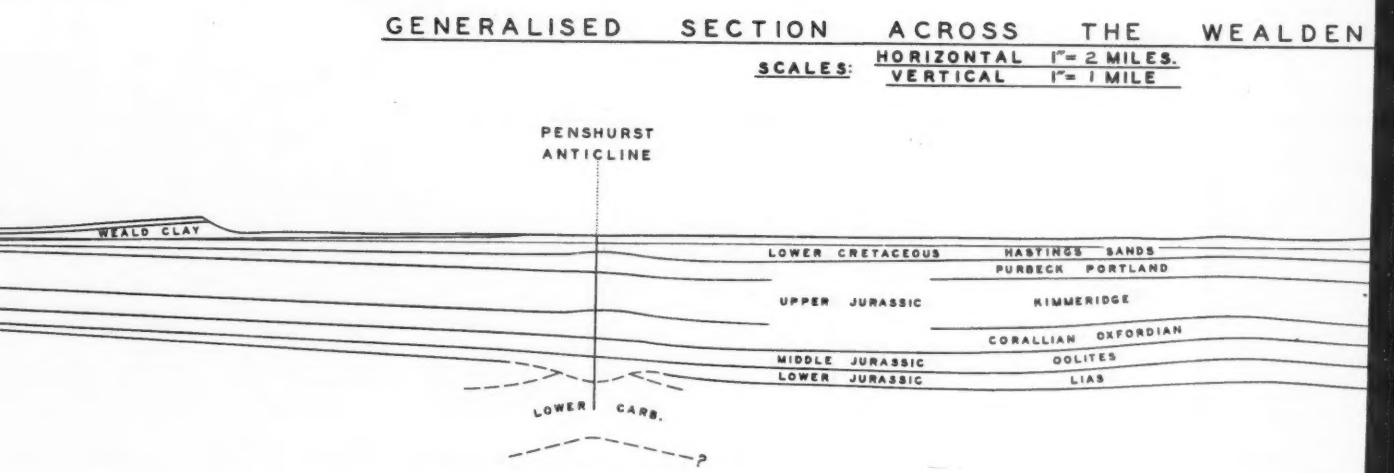
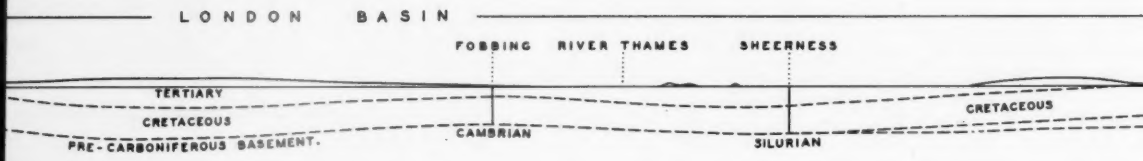


FIG. 16.—Section along line *IJ*, shown in Figure 2. Scale: horizontal, 1 inch equals 2 miles; vertical, 1 inch equ

SHALLOW PALAEOZOIC BASEMENT.

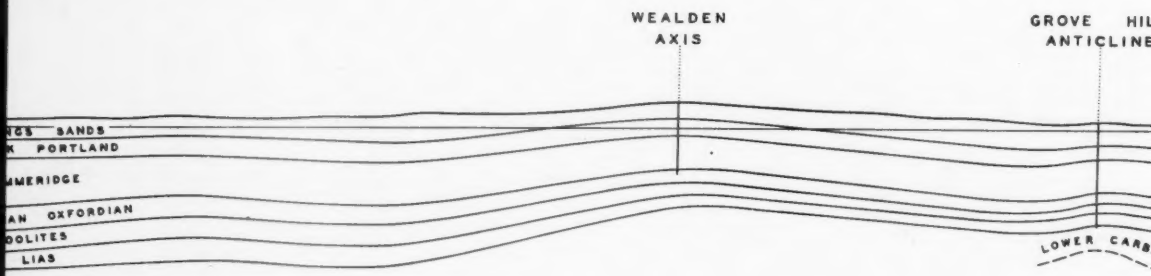
1"= 8 MILES.
1"= 1 MILE



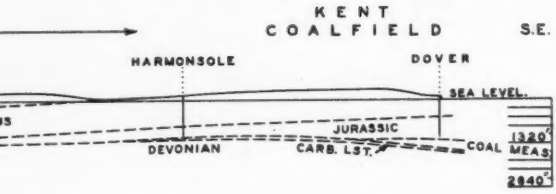
inch equals 8 miles; vertical 1 inch equals 1 mile.

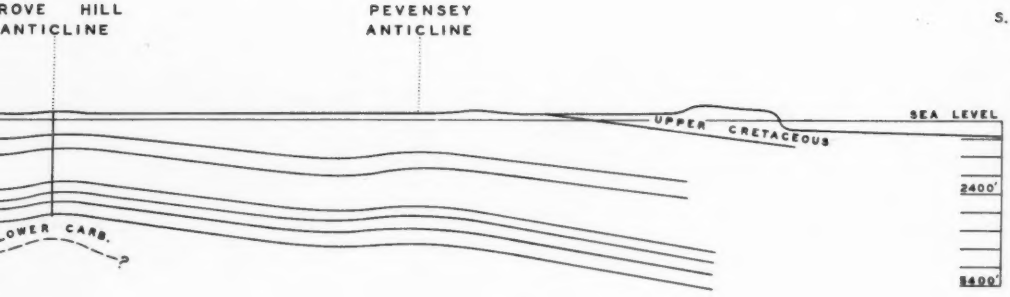
THE WEALDEN UPLIFT.

1"= 2 MILES.
1"= 1 MILE



nch equals 2 miles; vertical, 1 inch equals 1 mile.


KENT
COALFIELD
S.E.
HARMONSOLE
DOVER
SEA LEVEL.
JURASSIC
DEVONIAN
CARB. LST.
COAL MEAS.
1320'
2940'


ROVE HILL
ANTICLINE
PEVENSEY
ANTICLINE
S.
SEA LEVEL
UPPER CRETACEOUS
2400'
LOWER CARB.
?
3400'

remarks each major class is considered in turn and the most favorable choice is indicated.

A. CARBONIFEROUS PROSPECTS

These comprise in the main the Trias-filled depressions of central and northern England in which the Carboniferous lies unconformably below the younger cover. They are not, however, of equal grading and from every angle the folded Carboniferous rocks of the east flank of the Pennines lying beneath the East Midlands monocline is the first choice in comparison with the deep, strongly faulted basins of Cheshire, Lancashire, and Carlisle, with their virtually unknown Carboniferous development at depth.

The Staffordshire basin is in rather a different category from those previously mentioned in view of its proximity to the southern edge of the basin, and, although suitable anticlinal structures may be absent, yet the possibility of stratigraphic trapping within the Carboniferous against the rising Paleozoic floor is one which merits consideration. The occurrence of oil showings, however poor, does lend some additional attraction to this deep depression.

With reference to the East Midlands monocline, the exposed adjacent eastern flank of the Pennine uplift shows a very gentle regional dip of about 2°, on which are developed well defined anticlinal folds of considerable relief with adequate local closures. Colliery workings advancing eastward down the dip have traced the continuation of these structural conditions beneath the younger rocks of the monocline, and it seems reasonably certain that these may continue eastward for some distance. Post-Permian movements have affected this region very little apart from slight tilting in Tertiary time, and large-scale faulting in post-Trias time which is a feature of the western flank of the Pennine, is here virtually absent.

The all important point which may qualify the prospects of this region is the extent to which any oil or gas may have migrated toward the Pennine uplift, the highest structural elevation in the whole Midlands, prior to the development of sufficient western dip reversal, either plunge or flank, to the minor flanking structures. In other words, was there sufficient early Carboniferous movement proceeding concurrently with sedimentation and the possible formation of hydrocarbons?

The original oil search in England after the first World War was concentrated on the exposed Carboniferous structures developed on this regional eastern dip, among them being the Hardstoft, Ironville, and Ridgeway-Rennishaw folds; several of those tested were unclosed toward the west with consequent little chance of being productive while others had reasonable western closure and offered apparently reasonable prospects of production. Results were disappointing, however, as only one small productive well was drilled, on the Hardstoft dome, but showings of oil were reported in several holes both from the Millstone grit and Carboniferous limestone and the possibility that these folds were not originally sufficiently developed to trap Pennineward-migrating oil is thought to

be one likely source for the general failure of this drilling campaign. Farther east of this zone tested, beneath the Permian unconformity, the character of the Carboniferous fold structures is largely unknown although scattered bore holes suggest a reversal of dip and eastward rise in the vicinity of the River Trent. General considerations, however, lead to the conclusion that large closures developed by earlier movements might be present, and should an adequate cover of Coal Measures be preserved, then such prospects would be considered well worthy of testing.

Elsewhere, in southern England, the Carboniferous lies buried at considerable depth and its stratigraphic development is largely unknown. There is some reason to believe that the true Millstone grit may be missing over much of the region, as it is in Kent, although westward a pseudo-Millstone grit of Lower Carboniferous age may be present at depth below the Jurassic rocks of Worcester and Gloucester. There is a strong possibility that even if some development of this formation is locally present it does not represent a complete succession and does contain discordances and gaps. Continuation of the Armorican folds from western England and Wales eastward beneath the Mesozoic cover of southern England is very probable but it is believed that such folds would in many cases be eroded to a low horizon in the Carboniferous, an opinion which has been verified in two cases by actual drilling results. Altogether, the buried Carboniferous prospects of this region do not appear attractive, and beneath the Hampshire basin, for example, the depth of these rocks could vary from 7,500 to 10,000 feet.

A. JURASSIC PROSPECTS

Prospects of the buried Jurassic are confined almost entirely to southern England, although this formation is under cover of the Cretaceous along the eastern edge of the East Midlands monocline where, however, it appears to dip uniformly eastward where exposed, while when buried the overlying Cretaceous does not give any indication of regular folding apart from one rather indefinite anticline in Lincolnshire. Furthermore, there may be a considerable cut-out of the Jurassic section in the region of latitude 54° as is seen farther west at outcrop where, in crossing the intra-Jurassic axis of uplift near Market Weighton the section loses all the Middle and Upper Jurassic; this axis of uplift may extend eastward beneath the Upper Cretaceous for an unknown distance, and give rise to similar stratigraphic complications. Altogether it is not considered that this relatively small area of buried Jurassic rocks merits much consideration as a worth-while prospect.

The main Jurassic prospects occur in the Wealden area where, particularly in the southern and western portions, there is a thick marine section of these sediments, a number of well closed and relatively gently folded structures unaffected by any large-scale fracturing, and lastly a rather sporadic occurrence of oil indications, all of which factors together present a geological set up which offers considerable attraction as an oil prospect. This area is indeed the most obvious ob-

jective for testing in the United Kingdom from every point of view, and considerable prospects have been attributed to it by all operators. Among these structures may be mentioned the anticlines of Portsdown, Henfield, Kingsclere, and Hellingly as being particularly worthy of consideration.

The question of stratigraphic trapping all round the edges of the East Anglian platform against which the Jurassic sediments abut and disappear is one which merits consideration. Subsurface control, particularly on the southern edge of the platform, is relatively plentiful and the limits of the various members of the Jurassic can be reconstructed with some accuracy. Northward there is a very marked thinning of all members of the Jurassic which is due partially to reduced sedimentation and partly to the unconformity at the base of the Lower Cretaceous which cuts ever deeper stratigraphically into the Jurassic section toward the Paleozoic platform. Along the southern edge all members of the Upper and Middle Jurassic abut directly against the overlying Lower Cretaceous Wealden which bevels them all off in turn, while on the northwestern side of the platform there appears to be rather less regular arrangement of the Upper and Midde Jurassic with local intra-formational overlaps. Nowhere, however, does there occur a complete lensing-out of a particular unit with coverage by an overlapping series such as would constitute an ideal stratigraphic trap, except near the base where the lowest member of the Middle Jurassic overlaps the Lower Jurassic, although here as well there has been preliminary erosion of the latter sediments. The remote possibility of trapping in the Jurassic beds against the shallow Lower Cretaceous unconformity appears to have been explored adequately by numerous boreholes, and although traces of residual bitumen and odors of oil have, on occasion, been noted there is no oil in these sediments now.

B. CARBONIFEROUS PROSPECTS

Lower-grade Carboniferous prospects occur where sediments of this age crop out and have been subjected to a varying degree of denudation. Commencing with localities where a Coal Measure cover still remains, the South Wales basin presents the theoretically best example of this class of prospect. Here is a complete major tectonic unit with good structure and a thick Carboniferous section in which both Carboniferous limestone and Millstone grit are covered. Lack of significant oil showings is an adverse point, with also the possibility of meteoric flushing of possible reservoirs from north to south, but on balance the region merits a test.

Northward the only closures along the Pennine axis are exposed in low Millstone grit and are commonly strongly faulted, while the anticlines of the Craven Lowlands are with rare exception too deeply eroded to offer attractive prospects. The Bewcastle Fells present an unfavorable facies of Lower Carboniferous with, in any case, little or no favorable structure, and the last prospect in this class occurs in the Midland Valley of Scotland.

This region would not normally be considered as a likely prospect in view of

the unfavorable local facies of the Lower Carboniferous, the strongly folded nature of the country with an abundance of igneous material, and the general absence of simple unbroken structures. The occurrence of free oil, however, in the oil-shale field, and the presence of outcropping oil-impregnated sandstones of the Lower Carboniferous suggest that either oil-forming conditions, possibly restricted, were present in the Lower Carboniferous section, or that igneous distillation of the oil shales has given rise to large volumes of oil. From the commercial view-point the origin is of little moment so long as production is found, and for this reason the Midland Valley of Scotland, even with all its apparently adverse factors, is a prospect which merits investigation and possible drilling.

C. JURASSIC PROSPECTS

These are not considered to be of much importance. The only case of interest occurs on the Dorset coast where local movements of early Cretaceous age have folded the Jurassics into a series of rather steep anticlines within a restricted area south of Dorchester. Such early movement could possibly have been effective in trapping Jurassic oil which otherwise might have been dispersed. Denudation accompanying this movement has cut down into the Upper Jurassic but sufficient cover is left over the Middle and Lower divisions of this system for these structures to possess theoretically some prospects of containing oil.

D. PERMIAN (MAGNESIAN LIMESTONE) PROSPECTS

This facies of the Permian is restricted to the eastern side of central-northern England and the only portion of this region where it is anticlinally folded and under cover is in the Yorkshire basin. At the south in the Midlands monocline the Permian has a steady eastern dip with no minor folding and similar conditions prevail north of the basin in Durham where this rock is developed in its most favorable facies at outcrop. Prospects are, therefore, restricted to the anticlinal structures present within the Yorkshire basin of which the Eskdale anticline is the best defined and closed structure. The main Cleveland anticline in the center of the Yorkshire basin is certainly the largest fold but it plunges regionally eastward with no strong dip reversals, and although minor closures in the outcropping Jurassic are imposed on the main anticline they are not impressive, particularly when the effect of Triassic thinning on the projection of these surface closures to the Permian level has to be taken into consideration. No stratigraphic trapping is possible as the Permian crops out all round the basin edge.

E. LOWER CRETACEOUS (WEALDEN) PROSPECTS

These are restricted to those structures in the Wealden area, or their continuation westward, which have a good cover of the Upper Wealden clays still preserved or, better still, an Upper Cretaceous section present. Several of these anticlinal folds are present, of which the Portsdown and Kingsclere folds are the most attractive examples, with the Henfield anticline of lower grading on account

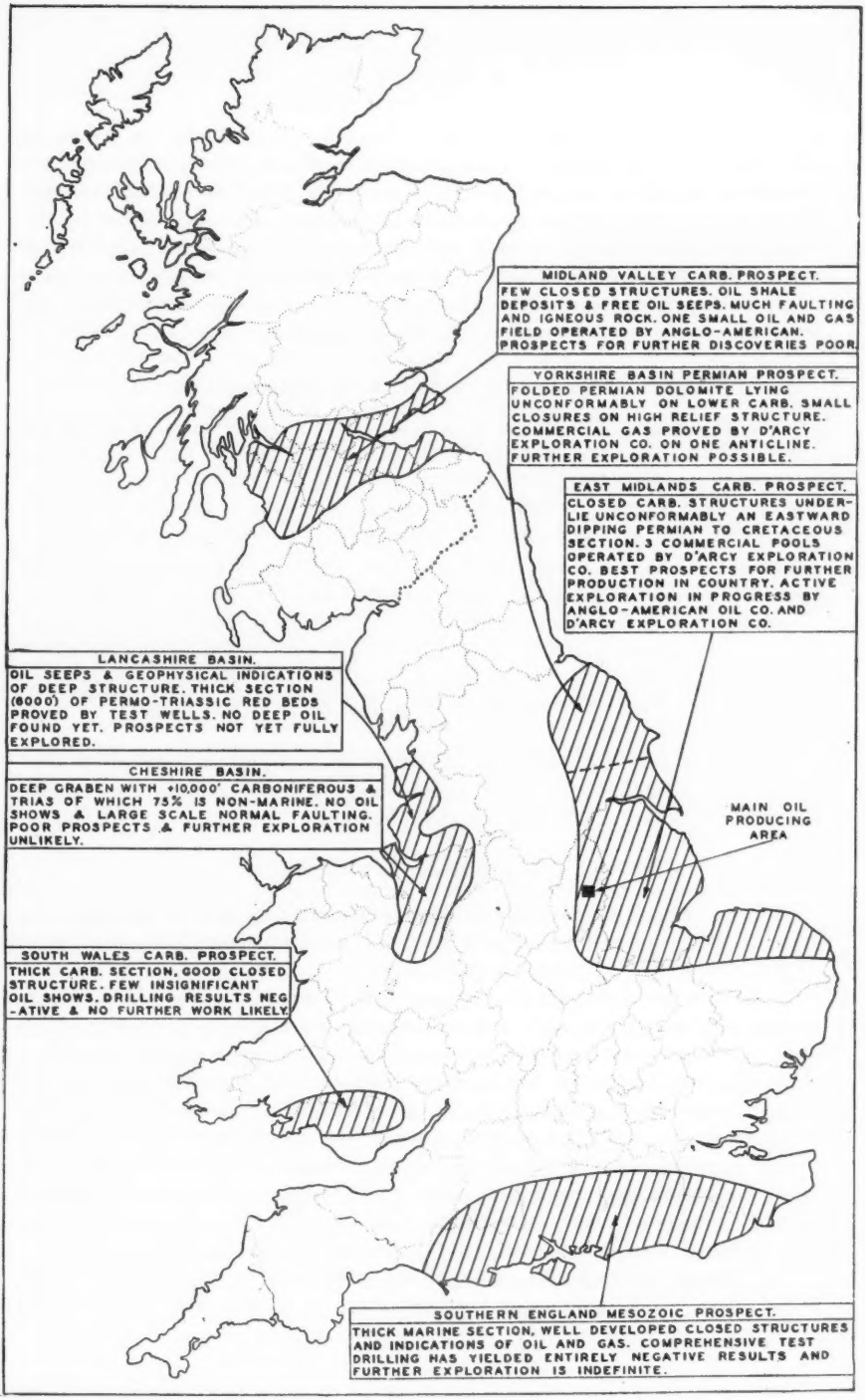

MIDLAND VALLEY CARB. PROSPECT.
FEW CLOSED STRUCTURES. OIL SHALE DEPOSITS & FREE OIL SEEPS. MUCH FAULTING AND IGNEOUS ROCK. ONE SMALL OIL AND GAS FIELD OPERATED BY ANGLO-AMERICAN. PROSPECTS FOR FURTHER DISCOVERIES POOR.
YORKSHIRE BASIN PERMIAN PROSPECT.
FOLDED PERMIAN DOLOMITE LYING UNCONFORMABLY ON LOWER CARB. SMALL CLOSURES ON HIGH RELIEF STRUCTURE. COMMERCIAL GAS PROVED BY D'ARCY EXPLORATION CO. ON ONE ANTICLINE. FURTHER EXPLORATION POSSIBLE.
EAST MIDLANDS CARB. PROSPECT.
CLOSED CARB. STRUCTURES UNDERLIE UNCONFORMABLY AN EASTWARD DIPPING PERMIAN TO CRETACEOUS SECTION. 3 COMMERCIAL POOLS OPERATED BY D'ARCY EXPLORATION CO. BEST PROSPECTS FOR FURTHER PRODUCTION IN COUNTRY. ACTIVE EXPLORATION IN PROGRESS BY ANGLO-AMERICAN OIL CO. AND D'ARCY EXPLORATION CO.
LANCASHIRE BASIN.
OIL SEEPS & GEOPHYSICAL INDICATIONS OF DEEP STRUCTURE. THICK SECTION (6000') OF PERMO-TRIASSIC RED BEDS PROVED BY TEST WELLS. NO DEEP OIL FOUND YET. PROSPECTS NOT YET FULLY EXPLORED.
CHESHIRE BASIN.
DEEP GRABEN WITH +10,000' CARBONIFEROUS & TRIAS OF WHICH 75% IS NON-MARINE. NO OIL SHOWS & LARGE SCALE NORMAL FAULTING. POOR PROSPECTS & FURTHER EXPLORATION UNLIKELY.
MAIN OIL PRODUCING AREA
SOUTH WALES CARB. PROSPECT.
THICK CARB. SECTION, GOOD CLOSED STRUCTURE. FEW INSIGNIFICANT OIL SHOWS. DRILLING RESULTS NEG-ATIVE & NO FURTHER WORK LIKELY.
SOUTHERN ENGLAND MESOZOIC PROSPECT.
THICK MARINE SECTION. WELL DEVELOPED CLOSED STRUCTURES AND INDICATIONS OF OIL AND GAS. COMPREHENSIVE TEST DRILLING HAS YIELDED ENTIRELY NEGATIVE RESULTS AND FURTHER EXPLORATION IS INDEFINITE.

FIG. 17.—Map summarizing present status of exploration in United Kingdom.
(1 inch equals 75 miles)

of the absence of any Upper Cretaceous. Anticlines located high on the flanks of the main Wealden uplift are open in the lower Wealden sandy beds which are the drilling objective, and are thus of no interest. The Wealden beds thin out and disappear northward toward the Paleozoic platform and are overlapped by the Upper Cretaceous, so that there is a possibility of the trapping of Wealden oil against this unconformity. The very attenuated Wealden series have been penetrated at many points in Kent, however, with no trace of any hydrocarbon being reported, so that this hypothetical prospect can be dismissed.

General Results of Present Exploratory Campaign

The present search for oil has been in progress for nearly 10 years and during this time widespread geological and geophysical investigations have been carried out by the operating companies. Numerous test holes all over the country have been drilled on the basis of this scientific exploration work which have provided a mass of information, and by now it is possible to review the results obtained and compare them with the theoretical prospects which have been deduced in the preceding portions of this paper. Undoubtedly some of the country has been condemned by this test drilling and the extent of possible future discoveries is considered to be circumscribed, but, apart from the unexpected and complete failure in southern England, the results so far obtained have followed broadly along expected lines though the size of the individual discoveries is possibly less than anticipated.

In the following remarks these results are discussed on the basis of the classification adopted for the selection of prospects, in order to facilitate the comparison of theoretical prediction and practical findings.

A. Carboniferous prospects

The only region in which this class has been given a really thorough test is the East Midlands, a condition which is the result of this prospect being of so much higher grading than any other in this category.

Extensive geophysical work has been carried out in the East Midlands including magnetic, gravimetric, and both refraction and reflection shooting. All of these methods have supplied some information, to a lesser or greater extent, but easily the most successful has been the refraction arc shooting technique developed by the D'Arcy Exploration Company which has delineated the relatively small structures developed on the Carboniferous limestone with a remarkable degree of accuracy for what is not, after all, a method of great refinement. Reflection shooting using modern equipment and technique has proved in general unsatisfactory, and even where results have been obtained they could not be relied on to give an accurate picture of the true structural conditions present.

The picture finally built up from all the geophysical work carried out in this region is one which is similar to that postulated by analogy with the structural

development of the exposed Carboniferous on the west. Eastward beneath the unconformity the Carboniferous rocks of the eastern flank of the Pennine uplift are folded and several high relief complex anticlinal uplifts have already been discovered. One of these ridges occurs in the Eakring region of eastern Nottingham as a steep-sided uplift about 2 miles wide with a maximum of 2,000 feet relief on the western flank, on which are developed a number of separate closures up to 500 feet. The D'Arcy Exploration Company have found production in four of these subsidiary structures on the main uplift, the oil being obtained principally from the upper part of the Millstone grit from an average depth of −2,000 feet, with a small amount from the basal Coal Measures in the largest of the four fields. Tests of Carboniferous limestone in these pools proved that this formation is water-bearing, although slight traces of oil have been recorded. To date a total of more than 2,000,000 barrels of good-quality mixed-base crude of average gravity 0.850 has been produced from an area of about 1 square mile in eastern Nottinghamshire.

This Eakring uplift is of considerable geological interest, occurring as it does on a gently dipping regional flank from which it rises sharply with marked effect. Other local closures, both on this feature and associated with it on the flanks at lower levels have been tested with no success to date, and it appears that the accumulation of oil in these small domes may be related to a unique combination of structural and stratigraphical factors in that this complex ridge probably underwent early movement contemporaneous with the Millstone grit deposition along an old Charnian line of weakness in the basement, and also that it formed the eastern edge of a trough of greatly increased deposition of the presumed source bed shales of the Millstone grit. Such a setup would be most favorable for the concentration of local oil pools and may well explain the restriction of the fields already found to this particular geological feature. Other high-relief structures lie buried beneath the younger cover but so far no production has been proved on any of them. In the northern part of the East Midlands region the Lindholme structure is a strong anticlinal fold which is developed for a considerable distance but is unfortunately much broken by faulting. It is now in process of being tested exhaustively by Anglo-American and in contrast to the Eakring uplift the potential reservoir beds should occur deeper on this structure around −4,000 feet. East of Eakring there is a large anticlinal uplift south of Lincoln which stands out as a strong magnetic and gravity anomaly probably related to the proved shallow depth of the basement beneath it. This structure is a steep-sided, broad-topped feature with small minor closures developed on it; several wells have been drilled by D'Arcy at various points on the crestal portion, one of which yielded a small production of oil in the Carboniferous limestone for a short time and then stopped. The Millstone grit has thinned to virtually nothing and abuts directly against the Permian unconformity on the Lincoln structure and has no possibilities.

Of the other Class A Carboniferous prospects, the Carlisle basin after detailed

gravity work is unlikely ever to be tested on account of adverse evidence from all aspects, while the Cheshire basin can be little better regarded though some further exploratory work will probably be carried out there. The Lancashire basin has been detailed by the gravimeter, and parts of it shot by the refraction arc method which indicated the presence of deep structure apparently aligned with the exposed Carboniferous folding of the adjacent Craven Lowlands, and possibly representing the buried continuation of one or other of these anticlines. Test drilling has shown a tremendous thickness of Trias and Permian redbeds underlain by a very hard siliceous formation of unknown age, the whole section showing no evidence of oil to a depth of more than 6,300 feet, apart from the surface oil showings in the Trias. The surface seepage area near Formby has been extensively drilled and a small shallow field operated by D'Arcy has yielded 45,000 barrels from a closure in surface Trias beds against the normal fault. Similar fault accumulations have been looked for in this area without success. The question of oil occurrence in the Lancashire basin is thus still a mystery and it is not easy to formulate any plausible hypothesis on which to base an exploratory program which has a reasonable chance of success.

B. JURASSIC PROSPECTS

The result of the Jurassic exploration of Class A grading constitutes the most disappointing feature of the British oil search. It may be realized from the foregoing discussion of the Jurassic formation in southern England that here were geological conditions which appeared to satisfy all the criteria for a potential petroliferous region. No geophysical work was needed in southern England as structural details could be clearly and accurately mapped by surface means supplemented on occasion by core drilling and hand-augering, and it could be assumed with some reason that such surface features persisted as closures to depths at which the prospective oil formations might be expected.

All types of anticlines in the Wealden uplift were tested, five wells being drilled to the pre-Jurassic rocks at depths varying from 3,500 to more than 6,000 feet. In all these holes no showings of oil of any significance were ever encountered in the Jurassic section and, as a result, this formation in southern England can be definitely written off as a prospect. The reason for this disappointing result is not clearly known although several possibilities can be advanced which may contribute some part of the story but which are not in themselves the sole cause for the non-occurrence of oil pools in this superficially attractive region.

Firstly, the sediments of the Jurassic section are generally of fine-grained textures in all the holes penetrated, arenaceous beds included; coarse sandstones, grits, and porous limestones with good reservoir capacity are absent and muddy silty sandstones constitute the best that can be noted as possible reservoir beds. Porosity in general is low throughout the section and permeability virtually lacking. Such lithological characteristics are not altogether unexpected when the derivation of the Jurassic sediments is considered, but even so the close-textured

nature of these beds is a factor whose degree could not be depicted prior to drilling. It is a question whether or not this handicap to fluid movement could be sufficient to prevent concentration of any oil formed, but in any case it is a factor which can not but be considered as adverse to the process of accumulation.

Another factor which may have played a part is the geological time which is thought to have elapsed between the deposition of the Jurassic sediments and the development of the subsidiary anticlines of the Wealden uplift. This feature was probably initiated in Cretaceous time and may have suffered submarine, and intermittently even sub-aerial, denudation in Tertiary time so that oil migrating updip to the highest point would have had chances of dispersal unless it was trapped downflank by structures which were sufficiently closed by this time to prove adequate barriers to flushing. In other words, the question of early structural movement, or lack of it, may have been of paramount importance here, as the time range from Jurassic to Miocene is of a magnitude which could afford every opportunity for the dispersal of whatever hydrocarbons were formed.

Lastly, there is the fundamental question of the original formation of free oil in the Jurassic section. Jurassic oil showings are sporadic in areal distribution though occurring throughout the system, but, on the other hand, the recurrence of oil shales throughout the section is so noteworthy and their development of so much more uniform distribution and extent that there is a most definite possibility that the Jurassic environment favored the formation of kerogen-bearing rocks from original organic matter rather than the conversion of this source material to liquid crude oil. Here then are three factors which may, or may not, play a part in the failure of the Jurassic system to yield oil and others, no doubt, can be proposed; it is doubtful, however, if a satisfactory solution to this problem will be found until more information of the fundamentals of oil occurrence is available.

C. CARBONIFEROUS PROSPECTS

These lower-grade Lower Carboniferous prospects have been given a less thorough testing, and so far only one success, and that but a small one, can be recorded.

In the South Wales basin the Millstone grit has been adequately tested on structure with entirely negative results but the Carboniferous limestone is still an unknown factor. General geological reasoning however suggests strongly that this formation has very scanty chances of success, and it is unlikely it will be tested for its own prospects alone. This result is not altogether unexpected in view of the absence of the potentially favorable basal shale section of the Midlands Millstone grit section, and the general lack of oil indications.

Elsewhere, the Carboniferous limestone has been tested on the western flanks of the Pennines under a thin Millstone grit cover, and although slight showings of oil were noted no oil was produced. Two tests of the Lower Carboniferous on gentle structures lying immediately north of the Derbyshire dome also showed

the Carboniferous limestone to be dry. In the Craven Lowlands several anticlines are present in which the Carboniferous limestone has a thin Millstone grit cover and it is possible the future may see some testing of these features.

Finally, a small oil accumulation was discovered by Anglo-American on the eastern side of the Midland Valley of Scotland near Dalkeith on a local closure along the axis of the high-relief Cousland anticline. This Midlothian pool is of insignificant dimensions, however, and has produced only 15,000 barrels of oil from a fine-grained sandstone in the oil-shale series of the Lower Carboniferous at a depth of −1700 feet. Other oil-impregnated sandstones occur in the section but yield no oil on test. Associated, however, with this one oil-producing sandstone are similar sandstones which contain natural gas under normal pressure, and which on test show an initial potential of several million cubic feet daily; attempts are being made to utilize these gas reserves by local industry. Analysis shows the gas to contain a slight ethane content with, however, methane forming the preponderant constituent. Midlothian No. 1 was drilled for some distance into the Upper Devonian, here conformable with the Carboniferous, but which in this well contained no trace of oil. The Midlothian pool is only a bubble of oil in a large closure and the total reserve is probably not more than 70,000 barrels, so that here is a case of oil occurrence which presents some interesting questions; is the oil the result of migration of igneous distilled crude away from the near-by oil-shale field, or is it formed *in situ* from the local Carboniferous section and if so, is there a relation between the small volume formed and the almost entire absence of oil shale in the Midlothian area?

A similar type closure on the same anticline several miles north of Midlothian has been proved by D'Arcy to contain gas also, but in this case there appears to be no associated oil although impregnations were noted in cores. Several other wells have been drilled in the Midland Valley but have not discovered any other production and it seems likely that here again a unique set of circumstances has given rise to the formation of this tiny pool and that the discovery of any other oil outside the oil-shale field, and its immediate vicinity is a questionable matter.

JURASSIC

The Middle Jurassic has been tested in Dorset on one of the early Cretaceous anticlines, open in the Upper Jurassic, without proving production; and this result is particularly disappointing in that no trace of oil was recorded in spite of the close proximity of a surface seep in a Middle Jurassic grit. Without entirely dismissing the Jurassic prospects in this region, they have certainly been diminished by this result.

PERMIAN (MAGNESIAN) LIMESTONE

In the Yorkshire basin two deep holes have been drilled to test the local dolomitic limestone facies of the Permian. The D'Arcy Exploration Company struck dry gas production in the Upper Magnesian limestone on the Eskdale

anticline at 4,200 feet with, however, no signs of oil. The gas was in considerable volume, initial tests indicating a daily rate of more than 2,000,000 cubic feet with normal closed-in pressure. This well showed that the hoped-for porous reef limestone comparable with the productive German Zechstein, and occurring at outcrop in Durham at the north, was not present in this well and the Permian was developed as a normal-type dolomitic limestone. Another deep hole was drilled by Gulf on a local "high" situated on the main Cleveland anticline and was also a dry hole although much structurally higher than the Eskdale well. This well, however, did encounter small gas showings in the Carboniferous beneath the Permian limestone.

Prospects of finding oil in the Yorkshire basin on the basis of the present results seem rather unlikely now, and the possibility of additional gas reserves being uncovered is restricted by reason of the general absence of well closed structures in this region. Further exploratory work, however, is still proceeding in this area and the prospects can not be said to have been entirely evaluated.

D. LOWER CRETACEOUS (WEALDEN)

The prospects of the basal Lower Cretaceous rocks have been explored in southern England in several wells, and, apart from occasional sporadic oil staining, nothing of any interest has been recorded; the impressive oil saturated sands cropping out in Sussex and Dorset being entirely absent at depth in these favorably located holes. The whole question of these Wealden oil sands remains, therefore, a mystery which is unlikely to be solved in the near future, and it seems probable that no oil pools are likely to be found in this formation.

In summary, it may be said that the two main theoretical oil prospects in the United Kingdom, one, the Carboniferous, has proved productive on a limited scale in a portion of the region believed to be potentially most favorable for this system, with a considerable area still to be explored and tested; while the other, the Jurassic, has proved to be entirely valueless. Of the remaining minor prospects it may be said that they have on the whole shown results which balance out in the final assessment. Some Lower Cretaceous production could with reason have been looked for, and yet nothing has been found, while, on the other hand, the Permian has been proved gas-bearing, if on a restricted scale, when in the beginning its prospects of containing either oil or gas might have been considered as dubious.

Possibly the most disappointing result after the complete failure of the Jurassic to yield any oil is the non-productive character of the Carboniferous limestone, once considered to be the main Carboniferous objective, and it seems logical to write down the prospects of this formation although it can not be entirely dismissed. The limestone is, in fact, a formation which ever flatters to deceive, oil stains and odors and even traces of liquid oil are frequently noted in it and undoubtedly reservoir capacity is present, yet out of a total of more than 20 structures tested, only in two cases have small quantities of crude oil been discovered, and in one of these the amount was so small as to be negligible. The operator, bearing in

mind the possibilities of limestone production, is always tempted to carry holes down to test it on structure, a process which adds considerably to drilling costs, as normally the lower part of the Millstone grit is harder and drills more slowly, with a lower footage per bit and per hour, than the overlying Coal Measures.

Conclusions

The final summing-up shows that England is now in the list of oil-producing countries albeit occupying to date but a lowly place among them. This status represents a compromise between the completely pessimistic views held by some authorities and the possibly over optimistic ideas entertained by others at the start of the present campaign; but it is thought that careful analysis of available data indicates that no really large-scale production could justifiably be expected and that the potential productivity of the United Kingdom must be limited in comparison with that of the major oil-producing countries. The exploratory work of all companies has been carried out on the best lines, utilizing the latest techniques of oil-finding and the most modern equipment, so that it is felt that any possibilities are now receiving a thorough and final investigation. The search is still on, further exploration both by geophysics and drilling remain to be carried out, and possibly additional Carboniferous production will be discovered.

Lastly, it might be noted that the absence of the true "wildcatter," or small independent operator, in this country tends to retard exploration when this is judged by the standards of the United States. The speculative "wildcatter" willing to drill outside chances which are in the nature of gambles is not encouraged to operate in the United Kingdom, and although the present system ensures the most scientific exploratory effort, this is, in effect, confined to the major oil companies. The "wildcatter," however, has considerable value in at least providing much valuable geological information which helps to amplify and assist in interpreting that obtained by the large operators, and his absence might mean that marginal production may actually be left unfound. In this connection the geologist will be the first to admit that even with the present progress in oil-finding there is much about the fundamentals of this art of which we are entirely ignorant, evidence obtained from any source is welcome, and it is always possible that the prospects condemned to-day may need to be reconsidered in the light of to-morrow's thought.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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PETROLEUM GEOLOGY OF AQUITAINE BASIN, FRANCE[1]

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ABSTRACT

The Aquitaine Basin in southwestern France, just north of the Pyrenees, is a large Mesozoic and Tertiary basin about 200 miles across. The French Government and private interests are presently exploiting parts of it for oil and gas in two concessions. One area of structures near the Pyrenees has already been proved to have commercial quantities of gas and is being actively developed.

The strata of greatest importance as containers of oil are the Jurassic and Upper Cretaceous. Of these two the Jurassic seems most promising. The possible oil-bearing strata are not thick presumably, and the Jurassic may be reached between 1,500 and 3,000 feet in the central part of the basin.

A zone of rather intense folding with gypsiferous shale in plugs or domes (Keuper shale of Upper Triassic) renders a piedmont or foothill belt to the Pyrenees not improbable for oil and gas discovery but so complex structurally as to be rather precarious for preliminary development. The area immediately north of the zone of plugs seems to be one of gentle folds and the most promising for immediate prospecting. It is extensively blanketed with alluvium and the structures will have to be defined mostly by geophysical prospecting or by shallow test drilling. The latter is well adapted to the region because of the abundance of microfossils in both the Tertiary and Cretaceous strata for subsurface correlation.

INTRODUCTION

GEOGRAPHY

The Aquitaine Basin lies in southwestern France just north of the Pyrenees (Fig. 1). It is closely related, in fact connected, with the well known Paris Basin. Both are large, gentle structural depressions and topographic lowlands. The Aquitaine Basin is 200 miles across, north and south, along the Bay of Biscay and approximately the same length east and west along the north flank of the Pyrenees.

The Garonne and Adour rivers drain large parts of the Aquitaine and take most of their waters from the Pyrenees. The Pyrenees are highest in their central part where a few peaks exceed 10,000 feet in elavation. The high Pyrenees were intensely glaciated, rise several thousand feet above timber line, support several glacierets, and look much like parts of the Alps.

The rivers are incised one to three hundred feet in a fairly even surface through much of the Aquitaine Basin. Toward the Pyrenees their vallys become deeper and the hills more rolling. From this gentle foothill belt the mountains rise abruptly in most places.

The central Aquitaine from the Adour River to the Garonne is a sandy plain known as the Landes. Outcrops are few in this area as well as in most of the Aquitaine Basin because of a cover of Miocene clays, sands, and gravels, and an extensive sand and gravel outwash of Pleistocene age, the so-called Sable des Landes.

[1] Manuscript received, February 26, 1946.

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OCCASION OF STUDY

The opportunity of reviewing the geology of parts of the Aquitaine Basin of France and the Pyrenees Mountains along the French-Spanish frontier was afforded the writer while teaching at the United States Army's Biarritz American University. The cliffs along the sea at Biarritz are classical for their nummulite-bearing beds of lower Oligocene and upper and middle Eocene age. These are the "Nummulitique" of the French, and have been worked in detail. In fact, there are about 1,000 papers on the geology and paleontology of the Aquitaine Basin and the Pyrenees. Reports by famous French geologists, J. de Lapparent, Douvillé, Termier, Fournier, Boussac, Lamare, Leon Bertrand, and Viennot, have been on this region. It has been a task to discover the important literature, and to gain an understanding of what has been done. Numerous field trips have helped relate the literature to the rocks. The writer has also had the valuable company of Professor Jean Cuvillier of the University of Paris on a number of trips and for several discussions. Cuvillier is in charge of the laboratories of the Societé Nationale des Pétroles d'Aquitaine at the city of Dax and is familiar with the stratigraphy and micropaleontology of the possible oil- and gas-bearing formations. The writer's colleague at Biarritz American University, Max White, has helped considerably in the translations, and Professor J. J. Galloway, also there, has assisted materially with the formational designations and the fossils.

The following is therefore mainly a review of what others have already done. It simply highlights those aspects of the geology that bear on the oil and gas prospects of the Aquitaine Basin.

NATURE OF STUDY

The French do not use the American system of naming formations, except in a limited way. In preparing an article for reading by American geologists the writer considers it necessary to conform to American style or risk misunderstanding. This situation has made it necessary to apply formational names to classical lithologic units of the Aquitaine Basin for which the French have found time or facies names satisfactory. The lithologic groups of beds are well known, but where exposed best along the cliffs of Biarritz and southward they had not been described and measured by units; therefore, the writer does not feel entirely presumptive in introducing formational names. Besides designating several formational names he also worked out originally a plug or dome of Triassic gypsiferous shale. Details of structure and history are clearer for this plug than for others nearby, and help define the history of the general zone in which they occur.

The bedrock geology of the Aquitaine Basin, as previously stated, is extensively covered by Miocene clays, sands, gravels, and peats, and by Pleistocene outwash. It seems futile to look for outcrops after riding over the basin, and one is surprised at the number that have been ferreted out. The small and scattered outcrops have made the geologic study one of paleontology and stratigraphic correlation. Fortunately, the Tertiary and Cretaceous rocks abound in fossils,

particularly Foraminifera, and the stratigraphic zoning of the fossils is well established by work in the Paris Basin, in England, in Germany and Switzerland, and in Mediterranean areas. The French geologists, therefore, have been able to recognize the stratigraphic position of the outcrops in the Aquitaine, but little is known about thickness.

HERCYNIAN OROGENY AND LATER BASINS

The geologic map of France[3] shows clearly the Hercynian orogeny of late Paleozoic time and the later basins whose sediments cover large parts of the Hercynian belts (Fig. 1). The discontinuity of the Hercynian folds and faults against the Mesozoic and Cenozoic strata is striking on the map, and a great unconformity is evident. The Hercynian folds of Brittany and of the Ardenne are believed to merge as the arms of a Y in the Central Massif. There, metamorphism and intrusion, and later Tertiary volcanism have largely obliterated the Hercynian pattern. An Hercynian highland existed in the site of the present Pyrenees but its trend and relation to the Hercynian highlands of the Central Massif and Brittany is not well known. Conglomerate and red sandstone and shale of "Permo-Triassic" age rest on the truncated edges of the "ancient crystallines" probably all of Paleozoic age and Hercynian metamorphism. The unconformity can be traced lengthwise of a good part of the Pyrenees and apparently indicates a landmass stretching along the central part of the range and spreading southward some distance. The landmass seemed to have remained out of water, at least in parts, until Upper Cretaceous time when it finally sank and was covered by the sea. Over it were deposited several thousand feet of massive limestones. The unconformity between these massive limestones and the ancient crystallines is very impressive in the high Pyrenees. Perhaps the history is not so simple as that of a highland gradually overlapped and finally buried. There probably were orogenic movements in the highland and adjacent basins because conglomerates whose pebbles consist of the ancient crystallines occur in the Upper Cretaceous of the Biarritz-Hendaye region.[4]

Although the Hercynian and Mesozoic history of the Pyrenees is not very clear it seems evident from inspecting the structural trends on the geologic map and the pre-Triassic unconformity around three sides of the basin that the Aquitaine Basin covers large areas of the Hercynian orogenic belts, and most everywhere the basin sediments rest on the ancient crystallines.

PYRENEES OROGENY

The Pyrenees are an early Tertiary mountain range, and part of the general Alpine system. In them the Mesozoic rocks have been highly compressed, folded,

[3] Carte Géologique de la France," 3rd edition (1933), *Ministère des Travaux Publics.*

[4] Jaques de Lapparent, "Terrains Crétacés de la région d'Hendaye," *Mémoires, la Carte Géologique détaillee de la France* (1918).

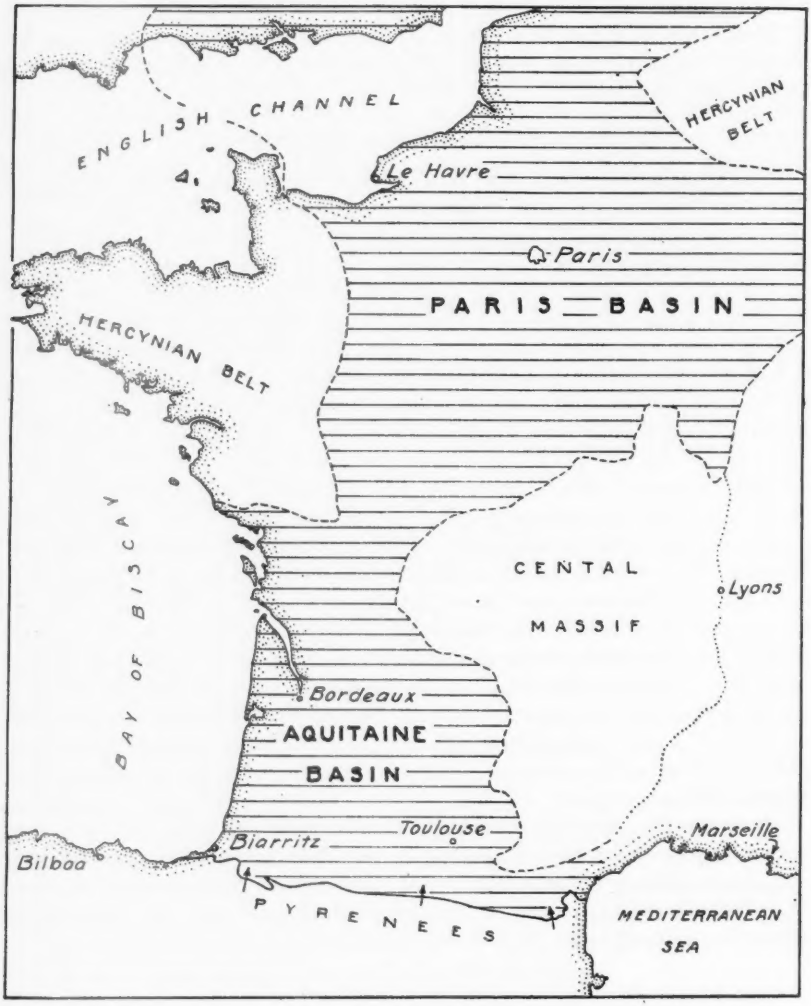

FIG. 1.—Map of France showing location of Aquitaine Basin and its relation to major surrounding structural elements.

and thrust-faulted. Much of the thrusting is toward the north, but some is toward the south (Fig. 6). Many fine publications concern the Pyrenees, chief among them from the areal mapping, structural, and stratigraphic points of view are the works of Leon Bertrand, [5] Eugene Fournier,[6] P. Viennot,[7] and Pierre Lamare.[8] These reveal an Alp-like structure in the Pyrenees with great "Nappes de charriage" and considerable rock flowage. A number of large plutons occur in the central and eastern part of the range.

In several places in the basin the middle Eocene beds rest unconformably on older rocks, and also the "Nummulitique" of middle and upper Eocene and lower Oligocene age is generally considered the orogenic sediment or molasse of the Pyrenees disturbance. It is probable, therefore, that the main orogeny occurred in the upper part of lower Eocene time.[9]

That the Pyrenees orogeny is superposed in part on the Hercynian is clear, but the relations are vague, and as far as can be learned, have not been very well worked out.

GENERAL STRATIGRAPHY OF AQUITAINE BASIN

STRATIGRAPHIC COLUMN

The stratigraphy of the Aquitaine Basin is summarized in Table I, The descriptions and thicknesses are taken from the exposures along the cliffs from Biarritz to Hendaye, except for the Permo-Triassic which crops out only in the Pyrenees. The variations of these formations and the presence of others are mentioned under succeeding headings.

PERMO-TRIASSIC STRATA

In the Pyrenees the rocks assigned to the Permo-Triassic by Bertrand and Viennot[10] are most commonly purple-red shales, sandstones, grits and conglomerates. Here and there they are very gray instead of red. The conglomerates are very thick in the eastern part of the western Pyrenees and attain a thickness there of over 3,000 feet.[11] Two divisions are recognized; at the base occur very large fragments of the underlying ancient crystallines, such as Carboniferous lime-

[5] Leon Bertrand, "Pyrénées Orientales et Centrales," *Bull. des Services, Carte Géologique de la France, 1908*, No. 118, Tome 18 (1906–1907).

[6] Eugene Fournier, "Pyrénées Basques," *Bull. des Services, Carte Géologique de la France, 1908*, No. 121, Tome 18 (1907–1908).

[7] P. Viennot, "Pyrénées Occidentales Françaises," *Bull. des Services, Carte Géologique de la France, 1927*, No. 163, Tome 30 (1927).

[8] Pierre Lamare, "Recherches Géologiques dan les Pyrenees Basques d'Espagne," *Mémoires de la Societé Géologique de France*, Nouvelle Série, Tome 12, Memoir 27 (1936)

[9] The term Paleocene is not generally used in France but is included in the lower Eocene. Professor Cuvillier has identified microfossils in beds that the French would call lower Eocene, but which Americans would probably call Paleocene, he says. The Paleocene strata are involved in the orogeny.

[10] P. Viennot, *op. cit.*

[11] E. Fournier, "Fenille de Mauléon," *Bull. Carte Geol. France*, No. 105 (1905), pp. 102–08.

TABLE I
STRATIGRAPHIC COLUMN AT BIARRITZ

Age	*Formation*		*Thickness (Feet)*	*Lithology*
Recent	No name		10–100	Beach sand and sand dunes
Pleistocene	Sable des Landes		10–200	Outwash gravel, sand, silt, and clay
Miocene	No name		10–130	Clays, marls, sandy marls, lignite
Lower Oligocene	Nummulitique	St. Martin siltstone	450	Silts, calcareous, gray massive, interbedded with gray limestone
		Biarritz sandstone	375	Sandstone, calcareous, tan to yellow, with irregular beds of limestone
Upper Eocene		Lou Cachaou limestone	155+	Limestone, gray, with beds of blue-gray calcareous silt
		Côte des Basques marl	1,700±	Marl, blue-gray, of varying composition. Some beds of clay, silt, and limestone
Middle Eocene		Peyreblanque limestone	50–200	Limestone, cream to buff, breccia in places at base. A lens of sandstone at top
Lower Eocene (Montian)	Bidart marl		125+	Marl, light gray, massive, 75% $CaCO_3$
Upper Cretaceous: Danian and Upper Senonian			1375	Marl, massive, mostly medium gray, some dull red. Pink unit at top. 50–70% $CaCO_3$
Upper Cretaceous: Lower Senonian and Turonian (?)	Bidache limestone		1,100+	Cherty limestone and interbedded dark gray shale (Flysch facies)
Middle (?) Jurassic	Limestone (no name)		100+	Limestone, lithographic, massive, black, and brown. Dark shale below
Upper Triassic	Keuper (?) shale		Fairly thick	Shale, red, gray, green, with interbedded gypsum and salt
Permo-Triassic	Buntsandstein (?)		Fairly thick	Conglomerate, grit, sandstone, and shale, mostly purple-red
Mostly Paleozoic and Proterozoic	Ancient crystallines		Thick	Phyllites, slates, marbles, quartzites, various intrusive rocks

stone and quartzite, Lower Devonian graywacke, Silurian phyllite (?), and quartz and granite. Above these occurs a conglomerate made up exclusively of pebbles of well rounded quartz. The cement is siliceous, commonly red. Lenses of red and light gray quartzite are common.

The rocks are barren of diagnostic fossils but they are generally considered Lower Triassic and perhaps in part Permian.

The red sandstones and conglomerates or their equivalents undoubtedly ex-

tend northward under the Aquitaine Basin, but they are nowhere exposed. Along the northeastern margin the Jurassic rocks overlap on the Central Massif and conceal the older Triassic. As far as a formational name is concerned the Geologic Map of France (1933) calls them the variegated sandstone (grés bigarré) and they have also been related to the Buntsandstein and Muschelkalk of Germany.

UPPER TRIASSIC STRATA

The Upper Triassic beds are a complex of varicolored marls[12] and dolomitic limestones that are gray, white, or yellow, cavernous, and commonly cellular. Where red colors predominate there is commonly much gypsum and, in some places, salt. This is the Keuper facies and the beds are usually referred to as the Keuper.

Shortly after the Keuper was deposited in the Pyrenees and the Aquitaine Basin it was intruded by numerous sills and dikes (perhaps other-shaped plutons) of a basic rock called ophite. Ophite is somewhat similar to diabase. The ophite masses are so common in connection with outcrops of the Keuper that their presence alone is taken to signify a Keuper exposure.[13] Ophite has the same stratigraphic significance as the varigated gypsiferous shales or marls.

The Keuper has flowed readily and a number of plugs or domes are known in the southern part of the Aquitaine Basin. They are the result of Keuper intrusions into the overlying Jurassic and Cretaceous strata. The ophite masses, seemingly always present where the Keuper occurs, have been carried along in the flowing and injecting Keuper.

JURASSIC STRATA

Jurassic strata crop out in the Pyrenees, and in various parts of the range all stages of the Jurassic from lower Lias to the Portlandian are believed to be present. They are chiefly blue and dark gray or black limestones, but dolomites, marls and shales are also common. The sequence is thin, probably not more than a few hundred feet thick. Viennot[14] reviews the distribution of the Jurassic in the Pyrenees and concludes that it is the deposit of a regressing sea from the former position of the Keuper transgressions, and furthermore, that a large area, the pre-Pyrenees, was probably out of water at the time and never received Jurassic strata (Fig. 2). It would seem, therefore, that the Jurassic deposits in the Aquitaine Basin might not be very closely related to those in the Pyrenees and the outcrops along the Central Massif are better related to the strata of the basin. Gignoux[15] reviews these briefly. The lower Lias is represented by marly limestone

[12] Marl is used in the French sense in this paper, namely, a sedimentary rock made up of $CaCO_3$ and clay with the $CaCO_3$ not exceeding 75 per cent. With more than 75 per cent $CaCO_3$ and with a light chalky nature it is called chalk.

[13] P. Viennot, *op. cit.*

[14] P. Viennot, *op. cit.*

[15] Maurice Gignaux, "Geologie Stratigraphique," 3rd Edition (1943). Published by Masson et C^ie.

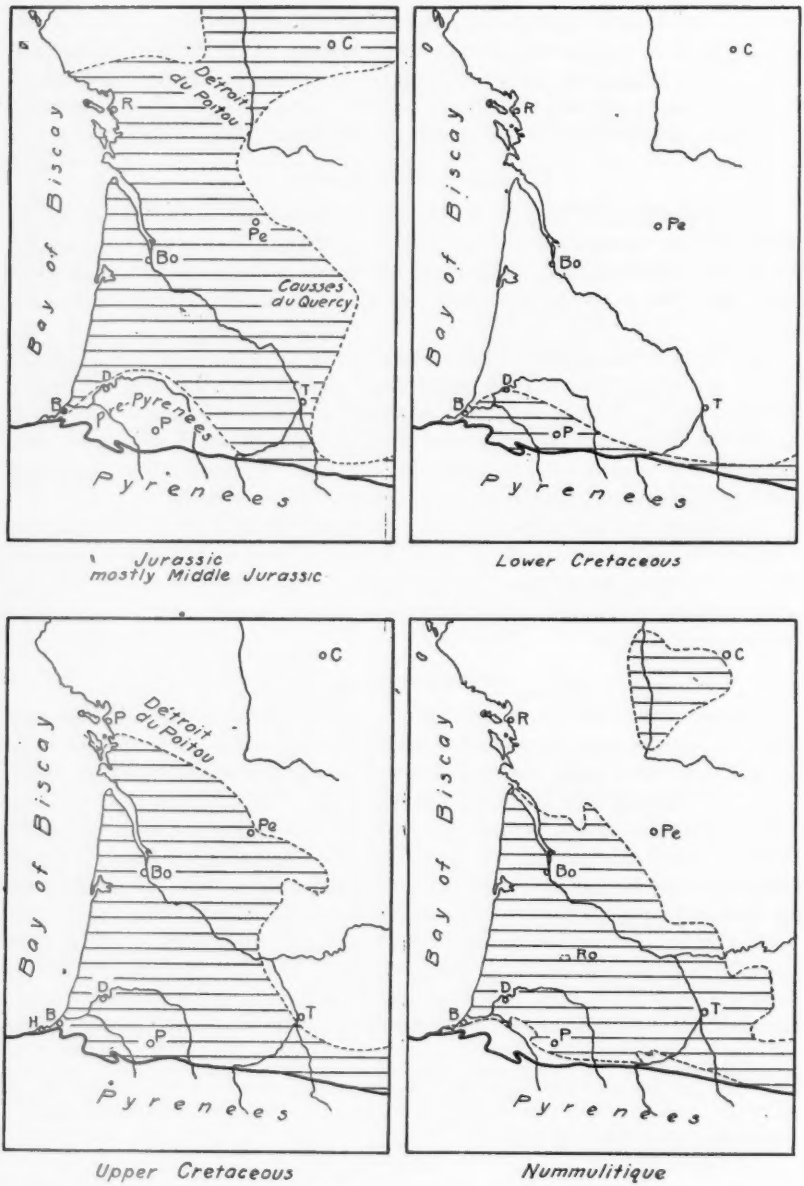

FIG. 2.—Map showing distribution of beds that have oil and gas possibilities in Aquitaine Basin. *C*. Chateauroux; *R*, la Rochelle; *Bo*, Bordeaux; *P*, Pau; *T*, Toulouse; *B*, Biarritz; *D*, Dax; *H*, Hendaye; *Ro*, Roquefort.

containing polypiers and *Gryphaea*. The middle and upper Lias is a very fossiliferous black marl, supposedly a deposit in deep water. On top of the black marl are the limestones and dolomites that make up the rest of the Jurassic, and which form the limestone plateau of the Causses du Quercy (Fig. 2).

Figures are not available on thickness of the Jurassic in the Causses du Quercy, but the relief is of such magnitude in this area of nearly flat beds that the entire Jurassic does not seem more than 500 feet thick.

In the exposure of black and sepia-brown lithographic limestone in the Ilbarritz plug near Biarritz (Figs. 3 and 4) the thickness is in excess of 100 feet. The lower part is cut off by a fault so the entire thickness is not known. The lithographic limestone is distinctly bedded but some beds are 10 feet thick. Under it are some black marly shales. The outcrops of these are commonly covered with beach sand but in 1911 they were fairly well exposed. (See Boussac's Pl. II, Fig. 1.)[16] Professor Jean Cuvillier has studied thin sections of both the lithographic limestone and the black shale, and reports no fossils in either. There are, however, acicular quartz crystals that seem to be syngenetic with the limestone and shale, and that may be diagnostic in well cores or drillings. The quartz crystals are apparent in thin sections, and are also visible in hand specimens. Some are 2 inches long and $\frac{1}{4}$ inch in diameter.

The basis for assignment of the lithographic limestones and dark shales of the Ilbarritz plug to the Jurassic is that similar beds are not known in the Triassic, Cretaceous, or Tertiary, but on the other hand, they are fairly similar to known lithologies in the Jurassic.[17]

LOWER CRETACEOUS STRATA

Throughout the Pyrenees the sediments of Aptian age rest on the Jurassic; strata of Neocomian age are unknown. The Cretaceous and Jurassic are for the most part conformable, and the Neocomian hiatus does not mark any important orogenic disturbance.[18] The Aptian beds are limestones and marls and abound in rudistids. In the eastern part of the pre-Pyrenees the limestones are thin, and black shales predominate. Westward in the Bayonne area limestones predominate. About midway between in the Orthez area three zones have been noted, namely, a lower limestone containing *Toucasia carinata* and *Horiopleura baylei;* a marl with *Hoplites deshayesi*, *H. dufrenoyi*, *Acanthoceras martini*, *Plicatula placunea;* and an upper zone of limestone with *Horiopleura lamberti* and *Polyconites verneuili*.[19]

The Albian is represented throughout the Pyrenees and pre-Pyrenees by a

[16] Jean Boussac, "Nummulitique de Biarritz," *Annales Hébert, Annales Stratigraphy et de Paleontologie, Faculté des Sciences de l'Université de Paris*, Tome V (1911).

[17] Personal communication, Jean Cuvillier.

[18] P. Viennot, *op. cit.*, p. 27.

[19] P. Viennot, *op. cit.*, pp. 29 and 30.

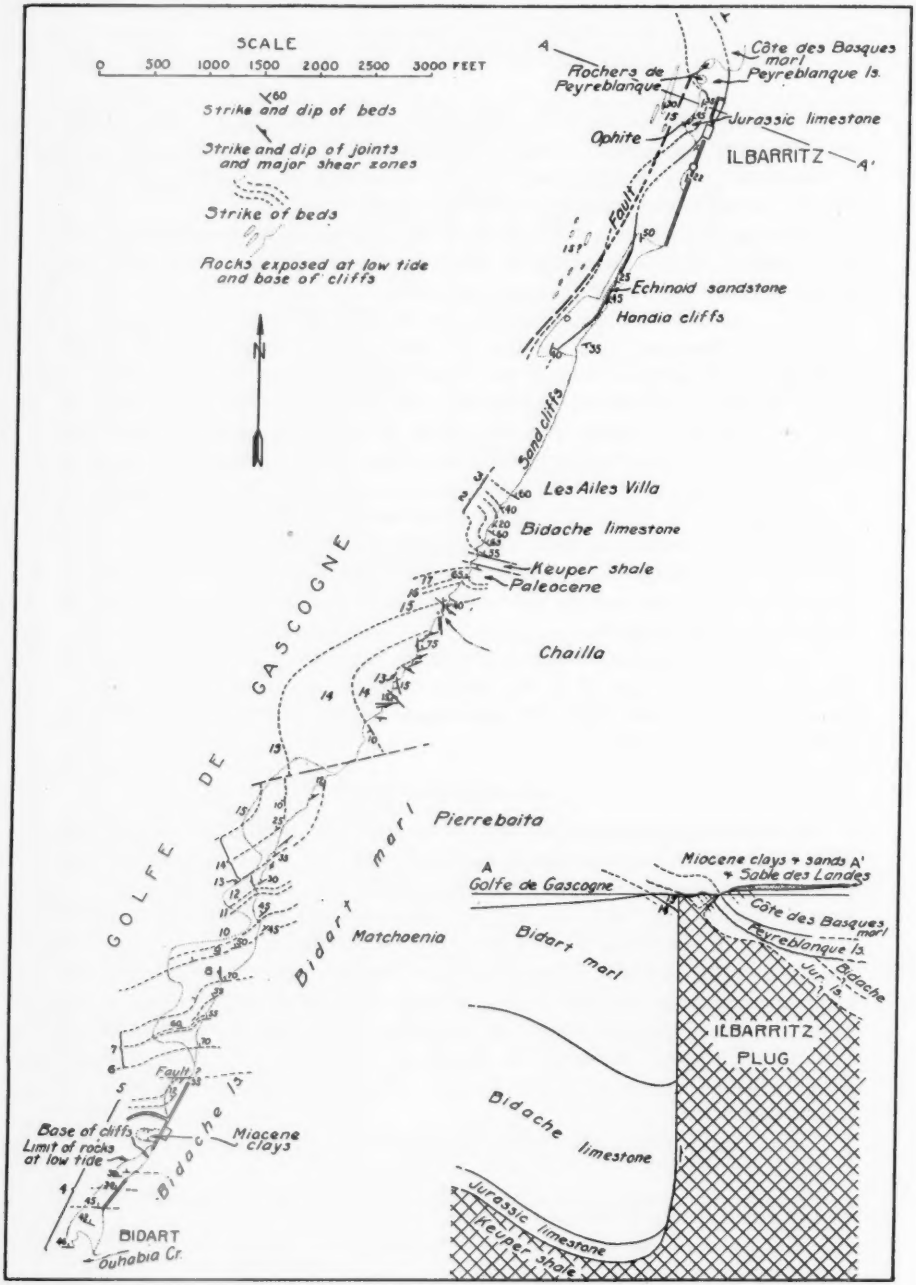

FIG. 3.—Geology of shoreline between Ilbarritz and Bidart, just south of Biarritz. Pace and compass traverse by A. J. Eardley. Units of Bidart marl and Bidache limestone correspond with those of cross section *AA'* and with cross section *B' B''* (Fig. 4). Refer to text for description of each unit.

very thick deposit of black, thin-bedded shale with thin intercalations of limestone, sandstone and conglomerate. In the vicinity of Bayonne it is sandy.

Some gray limestone beds in the western Pyrenees may be transitional from the Albian to the next younger Cenomanian, but complicated structures and a poverty of fossils renders their stratigraphy difficult.

Along the entire northeast edge of the basin the Upper Cretaceous rests on the Jurassic; no Lower Cretaceous beds crop out. The problem arises, therefore, how far northward and northeastward does the Lower Cretaceous extend from the Pyrenees.

The distribution map (Fig. 2) shows a limited extension, hardly to Biarritz and Dax. This was arrived at circumstantially. In the zone of Keuper plugs (Fig. 6) the Lower Cretaceous appears in connection with most of the known Keuper exposures along the southern part of the belt but not with those along the northern part. Also in connection with the Ilbarritz plug (Fig. 4) although no exposure of the contact of the Upper Cretaceous and the Jurassic occurs, there seemed to be no logical way of showing in cross section or ground plan a formation of Lower Cretaceous age, at least a *thick* formation. The general distribution of the Lower Cretaceous, therefore, in the zone of Keuper plugs and its increasing sandiness toward Bayonne have induced the writer to show the limited extent pictured in Figure 2. Wells drilled in the basin north of Dax, however, may show its presence there, but it is not expected.

UPPER CRETACEOUS AND LOWER EOCENE STRATA

Along the northern border of the Aquitaine Basin the Upper Cretaceous deposits crop out in a narrow border and represent a marine transgression beginning with the Cenomanian. The sands and lignitic clays at the base indicate littoral conditions and the beginning of the transgression. They contain pieces of amber, *Acanthoceras rothomagense*, and *Schlönbachia varians*. On these come the first rudistid limestones with *Ichthyosarcolithes*, *Praeradiolites*, and *Caprina*. Then come layers of sand with an oyster fauna, and finally the second rudistid limestones.[20]

The transgression came from the Atlantic and advanced to the southeast across the Aquitaine Basin. Gignoux recognizes this because the beds near the present ocean shore are more marly and of deeper-water deposition than the lignitic littoral facies on the southeast.

The Turonian is represented at the base by marly limestones containing *Inoceramus labiatus*. On the *Inoceramus* limestones occur the rudistid limestones with the first hippurites and radiolites.

The Senonian beds overlie the older beds disconformably, but the overlapping is slight. They represent a new transgression of the sea. The extensive surfaces in the northern part of the Aquitaine Basin not formed by the Tertiary are in the

[20] Maurice Gignoux, *op. cit.*, p. 414 and Fig. 94.

Senonian. The beds are sandy limestone and limestone with veritable reefs of rudistids. Fossils are numerous, and the Coniacian, Santonian, and Campanian stages are recognized. The Danian is absent along the northern edge of the basin but present in the southern part. Thicknesses for the Upper Cretaceous strata are not given in the literature, as far as can be ascertained.

The Upper Cretaceous is believed to be largely transgressive toward the south, and discordant on its substrata. At least, Gignoux[21] is of this opinion, and states that a period of folding and erosion in the Pyrenees intervened between the Lower and Upper Cretaceous. The lowest of the Upper Cretaceous strata in the Biarritz-Hendaye region appear to be Senonian,[22] and Turonian. The Cenomanian and perhaps part of the Turonian are absent. The lowest formation is the Bidache limestone (calcaire de Bidache) described by Stuart-Menteath,[23] Douvillé,[24] Viennot,[25] de Lapparent,[26] Lamare,[27] and others. It is an assemblage of marly shales, sandy shales, sandstones, limestones, and locally beds of conglomerate and breccia. Dark gray or black chert lenses, beds, and nodules are very conspicuous and abundant in the limestone along the Biarritz-Hendaye coast. The thin and regular beds of these intercalated lithologies reminded Stuart-Menteath of the flysch of the Alps, and since the time of his work in the pre-Pyrenees the Upper Cretaceous, especially the Bidache, has been called the flysch, which in this usage is purely a facies designation. The beds above the Bidache limestone are mostly very massive marls, generally gray but with some dull red units, and are not characteristic flysch. They range in age from Upper Senonian to the lowermost Eocene. This marl sequence has been called the Bidart marl.[28]

The section measured along the coast south of Biarritz by the writer is as follows. Figure 3 is a detailed traverse of the beds and shows the location of outcrop of each of the units described below except unit 2 whose description comes from the cliffs of the shore just south of Ouhabia Creek (Fig. 5).

The minimum thickness of the Bidache in the Bidart area is about 1,000 feet. It may be considerably thicker. The thickness of the Bidart marl above, which includes part of the Senonian, the Danian, and part of the lower Eocene, is approximately 1,500 feet. As far as observable, there is no physical indication of a break in the sequence. It will be considered inadvisable to include beds of both

[21] Maurice Gignoux, *op. cit.*, p. 415.

[22] Eugene Fournier, *op. cit.*
Pierre Lamare, *op. cit.*

[23] P. W. Stuart-Menteath, "Sur les lignes directrices des environs de l'Observatoire d'Abbadia (Basses-Pyrenees)," *B. S. G. Comptes rendus sommaires* (Mai, 1894).

[24] H. Douvillé, "Les marbres de Sarrancolin et de Saint-Beat dans les Pyrenees centrales," *CR. Ac. Sc.*, Tome 193 (1926), pp. 826–30.

[25] P. Viennot, *op. cit.*, p. 32.

[26] Jacques Lapparent, "Etude lithologique des terrains Cretaces de la région d'Hendaye," *Memoirs, la Carte Géologique détaillee de la France* (1918).

[27] Pierre Lamare, *op. cit.*

[28] Pierre Lamare, *op. cit.*

SECTION FROM ILBARRITZ TO BIDART ALONG COASTAL CLIFFS

Unit	Thickness in Feet
Bidart marl	
17. Chalk, marly, light gray. 75% $CaCO_3$. Paleocene (Cuvillier) Top cut off at Ibarritz plug	125+
16. Marl, chalky, nearly white, massive. 67% $CaCO_3$. Also Paleocene (Galloway)	50
15. Marl, in part pink or salmon colored. 57% $CaCO_3$. Danian (Cuvillier)	75
14. Marl, medium gray, very massive. 50% $CaCO_3$. Upper Senonian (Cuvillier)	250
13. Limestone conglomerate, syngenetic, probably present only locally	3
12. Marl, Ditto 14. Upper Senonian	60
11. Marl, massive, dull red	25
10. Marl. Ditto 14. Upper Senonian	125
9. Limy marl, hard, and shaly marl, soft. Beds blue-gray, 1 to 2 feet thick and regularly interbedded. *Inoceramus*, *Cancellophycus* and *Jeronia* numerous	150
8. Marl, shaly, massive, blue-gray with some dull red beds. Weathers to slope	150
7. Marl, massive, cliff-maker, gray and dull red	280
6. Phyllite conglomerate. Made up dominantly of dark gray and black phyllite fragments, conspicuously tabular, with edges and corners slightly but smoothly rounded. Also many fragments of a pinkish cream-colored, fine-grained marble, somewhat better rounded than the phyllite pebbles. Also several varieties of metaquartzite. Fragments range from ¼ to 6 inches in diameter, with dominant size about 2 inches. Cementing material is marl, same as that of units immediately above and below. In places, cement is more abundant than pebbles. Conglomerate seems to be channel-fill and at two horizons about 25 feet apart. Upper Senonian (Cuvillier)	1–4
5. Shale, marly with some marly limestone beds, gray. Transition to Bidache limestone, units 4–1. Limestone beds become more abundant toward bottom of unit 5, shale less abundant and less marly, and dark chert lenses in limestone appear	200
Bidache limestone	
4. Flysch. Intercalated rather thin but regularly bedded limestone and shale. Beds are 2 or 3 inches to 2 or 3 feet thick. Limestones are blue-gray, may be a little marly but some look fairly pure, and they contain beds, lenses, and nodules of dark chert 1 to 6 inches thick. Base not exposed. Covered at mouth of Ouhabia Creek	500
3. Flysch. Ditto No. 4. Mostly covered. Thickness not known	100+
2. Shale, gray, and limestone, light gray and tan. Very little chert and dominance of shale distinguishes this unit from 4	225
1. Flysch. Ditto 4. Units 1–4 are Bidache limestone	50+

Eocene and Cretaceous age in a single formation, especially when fossil evidence is present and clear that the beds transcend a systemic boundary, but the writer prefers to give greater weight to the lithology, which is not sufficiently variable to permit, with present information, the division of the sequence.

An interesting unit of beds is associated with the Bidache from the beach at Bidart southward along the coast. It is a clay of yellow, rusty, and gray-blue color with beds of chert. The chert occurs at intervals about like that in the Bidache and looks outwardly identical with that of the Bidache. At first, the clay and chert unit seemed to be part of the Bidache. As samples of the clay yielded no microfossils,[29] however, the area was re-examined. Although evidence is not clear the writer's final conclusion is that the unit is part of the Miocene clays, and rests unconformably on or against rather steep slopes in the Bidache. It is also

[29] J. J. Galloway, oral communication.

possible that faulting has brought the Bidache and the Miocene into contact, because the line of separation is fairly straight for over a mile. Since the yellow clay and chert seems tilted, an episode of folding apparently followed the deposition of the Miocene clays, but before this conclusion can be accepted the area deserves greater study. Details of the geomorphic history are here to be found if someone wishes to work them out.

A somewhat similar sequence of Upper Cretaceous beds has been studied by de Lapparent[30] in the Hendaye region about 20 miles southwest of Biarritz (Fig. 2). Limestone breccias are abundant there in the flysch and in beds perhaps equivalent to the Bidart marl. The breccias have interested de Lapparent most. He concludes that they are syngenetic with the associated limestones and were formed as follows. At a considerable distance from shore in a part of the sea whose plankton contained much sea weed (*Cancellophycus*) an anticlinal ridge began to rise. Strong currents of storm origin demantled the ridge and carried the calcareous fragments toward shore along with much of the open sea plankton. Soon calcareous reefs formed on the rising ridge. These, too, were broken by storms and deposited in the littoral as part of the "breccia." Only one thin bed of syngenetic breccia was seen in the Bidart section (unit 13), and somewhat farther north near Dax in the Tercis anticline none of the breccias has been noted. It is generally believed that the flysch facies, with the breccias, or syngenetic conglomerates, grade toward the north in the Aquitaine Basin into marls, shales, and limestones.

The Upper Cretaceous flysch is replete with *Globotruncana* (called "rosalines" by de Lapparent), *Gümbelina* (called *Textularia*) and "lagenas." According to J. J. Galloway[31] the lagenas of de Lapparent are probably other forms. The writer is also indebted to Professor Galloway for the information on de Lapparent's use of the names *Rosalina* and *Textularia*.

The Upper Cretaceous beds are possible oil- and gas-bearing rocks in the Aquitaine Basin and they have been the subject of much study lately by the French stratigraphers.

MIDDLE AND UPPER EOCENE AND LOWER OLIGOCENE STRATA

The "Nummulitique" of the Biarritz coast consists of beds of middle and upper Eocene and lower Oligocene age and is replete throughout with fossils, especially Foraminifera. It has been studied in detail by Boussac[32] and Heron-Allen and Earland[33] and others have traced it throughout the Aquitaine Basin. North of Dax it blankets the Cretaceous completely except for the borders of the basin and for one small exposure at Roquefort (Figs. 2 and 3). At Biarritz it is

[30] Jaques de Lapparent, *op. cit.*

[31] Personal communication.

[32] Jean Boussac, *op. cit.*, p. 89.

[33] E. Heron-Allen and A. Earland, "Foraminifera of the Côte des Basques, France," *Mem. Proc. Manchester Lit. Phil. Soc.*, Vol. 62, No. 6 (1918).

approximately 2,800 feet thick and consists of marine limy siltstone, marl, limestone and calcareous biostroms, and sandstone. Details of the section there from bottom to top are as follows.

SECTION FROM ROCHERS DE PEYREBLANQUE TO CHAMBRE D'AMOUR, BIARRITZ, FRANCE

Peyreblanque limestone.—Named from Les Rochers de Peyreblanque where the beds are best exposed (Fig. 3). Massive, generally very fine-grained, light gray, tan, and cream-colored. *Nummulites aturicus* and *N. perforatus* common. In places at the base a limestone breccia is prominent. Its fragments consist mostly of the same kind of limestone as the cement, are fairly angular, but in places the fragments of the underlying Jurassic (?) limestone make up most of the breccia. The surface on which the Peyreblanque limestone rests is a cavernous and pitted solution surface in the Jurassic (?) limestone, and the local relief at the time of burial may have been as much as 200 feet. The distribution of the limestone may be entirely limited to the area of the Ilbarritz plug (Figs. 3 and 5). That the unconformity is of wider significance, however, has been confirmed by Professor Cuvillier and co-workers[34] but the relations generally involve other beds. It is not certain that the Nummulitique has been seen in any exposure resting directly on the lower Eocene (Paleocene or Montian (?)) but it must so occur in many parts of the basin, particularly north of the zone of Keuper plugs. This will be determined only by the drill.

The Peyreblanque limestone ranges from 50 to 200 feet in thickness where exposed.

At the base of the Handia cliffs the Peyreblanque contains much sand at the top with numerous echinoids. It is referred to there as the echinoid sandstone,[35] but probably is of very local extent.

Boussac determined the age of the Peyreblanque limestone and lower beds of the Côte des Basques marl that overlie it as upper Lutetian in age. The Lutetian is middle Eocene.

Côte des Basques marl.—The Côte des Basques marl is here set off as a formation because it represents an easily recognized lithologic unit. It is overall-blue-gray and consists principally of marl and calcareous clay. It is approximately 1,700 feet thick. The beds in the middle part contain mostly clay, some are silty, and a few resistant beds of limestone are intercalated. The lower 200 directly over the Peyreblanque limestone, is harder and more limy than the beds above. The Rochers de la Goureppe are composed of these strata. The formation is exposed in the cliffs of the Côte des Basques from the Rochers de Peyreblanque and la Goureppe to the fault at Lou Cachaou (Fig. 5).

The marls are profuse with fossils which Boussac and Douvillé have identified

[34] Personal communication.

[35] Jean Cuvillier, personal communication.

TABLE II

NUMMULITIQUE AT BIARRITZ

Epoch	Formation Names	Stage Gignoux	Stage Boussac		Fossils (Boussac)
Lower Oligocene	St. Martin siltstone	Upper Stampien* Lower Stampien Upper Sannoisien	Chattien (?) Rupelien		*Num. intermedius, vascus, bouillei, Clypeaster pentagronalis, Pecten arcuatus, Chlamys bellicostata, Ostrea cyathula, Turritella asperula, Scalaria pellati, Tritonium delbosi, Athleta subambigua*
	Biarritz sandstone	Lower Sannoisien	Lattorfien		*Num. intermedius, vascus, bouillei, Eupatagus ornatus, Scutella subtetregona*
Upper Eocene	Lou Cachaou limestone	Ludien	Priabonien	Ludien	*Num. Fabianii* type and mut., *N. rosai, N. bouillei, Echinolampas cachaouensis, Sismondia planulata; Chlamys biarritzensis* mut., *Ostrea bouillei*, etc.
	Côte des Basques marl	Lédien	Priabonien	Bartonien	*Num. fabianii, rosai, bouillei; Pecten arcuatus, Chlamys biarritzensis, Cardita hortensis, Diatoma elongatum, Cerithium hortense, Newtonella bajoensis, Solarium lucidum, Turricula scalarina, Pleurotoma odontella, Clavatula praepustulata, Bathytoma turbida, Borsonia hortensis, Conorbis dormitor, Ancilla priabonensis*
			Auversien		*Num. perforatus, N. striatus; Clypeaster (Biarritzella) marbellensis, Spondylus bifrons* mut. *palareensis, Lucina pulliensis, Cerithium gentili, C. johannae, C. biarritzense, C. bouillei, Turritella inscripta, Beloptera biarritzensis*, etc.
M. Eocene	Peyreblanque limestone	Upper Lutetien	Upper Lutetien		*Num. millecaput, brongniarti, perforatus, atacicus; Porocidaris pseudoserrata, Echinanthus pellati, Amblypygus dilatatus, Macropneustes brissoides, Prenaster alpinus; Chlamys paveri, C. subtripartita, Spondulus redlichi, Pleurotomaria lamarcki*

Unconformity.

* French spelling of stage names

and described, but not zoned in detail. They are Priabonian (upper Eocene) in age, except for the lower 200 feet approximately, which is upper middle Eocene.

Fossils from the upper 1,000 feet approximately are summarized in the accompanying chart of the Nummulitique (Table II). This much of the formation is upper Lédien.

In the next lower part of the formation, perhaps from 200 to 700 feet above the base fossils of lower Lédien and upper Lutetien age occur (Table II).

Lou Cachaou limestone.—Above the Côte des Basques marl is the Lou Cachaou limestone, named from Lou Cachaou, the large rocks off the southeast corner of Biarritz Point. See map, figure 5. The limestone formation is also exposed in the

cliffs along the south side of Biarritz Point, a segment of the coast called "Perspective Miramar." Boussac[36] has described the beds of Lou Cachaou in great detail and recognizes the contact between the limestone and the overlying Biarritz sandstone as the division between the Eocene and Oligocene. This contact may be seen at the foot of the narrow stairs from the promenade to the rocks and sea-cave below, just at the old Villa Belza. A rusty yellow sandstone with numerous pebbles (the base of the Biarritz) rests on a blue-gray silty marl (the top of the Lou Cachaou), and the contact is easy to locate.

The Lou Cachaou limestone is made up of alternating beds of resistant limestone and non-resistant silty marl. The proportion of each is about 50 per cent, but the limestones are very conspicuous and there is much calcium carbonate in the marls, so the designation of the formation as a limestone—Lou Cachaou limestone—seems proper.

The limestone is gray with some beds weathering tan. It is hard and very fossiliferous. Some beds are biostroms (calcairè organogène) chiefly of foraminifera. The marls are a mixture of silt, clay, and calcium carbonate, are somewhat cemented, but the point of the geologist's hammer sinks in about an inch with each hit. Some of the marls break down when soaked in fresh water, and the Foraminifera are cleanly released. Some of the marls are so silty that the term siltstone might be more appropriate than marl. They are all gray or blue-gray, and nearly all very fossiliferous.

Characteristic fossils are: *Nummulites fabianii* type and mut., *N. rosai, N. bouillei; Echinolampas cachaouensis, Sismondia planulata; Chlamys biarritzensis* mut., *Ostrea bouillei, et cetera.*

Boussac measured 155 feet of beds in Lou Cachaou. It is probable that additional beds, below those exposed and now under water, might also belong to the Lou Cachaou limestone, and that a thickness in excess of 155 feet is present. All of the beds are probably present in the cliffs of Perspective Miramar including the contact with the underlying Côte des Basques marl, but they are there mostly covered with masonry retaining walls, gun emplacements, and vegetation.

A very sharp flexure that may have broken into a fault has displaced the Lou Cachaou limestone opposite the Biarritz sandstone at the west end of the Perspective Miramar. All of the beds, save perhaps some at the base of the Lou Cachaou limestone, are exposed, however.

Biarritz sandstone.—The Biarritz sandstone is generally fine-grained and tan to rusty yellow in color. Its only exposure along the coast is in Biarritz Point but there, almost the entire section can be seen, and is 375 to 400 feet thick (Fig. 5). At the top the sand is very fine and may be gradational into the overlying St. Martin siltstone. A covered interval of about 75 feet intervenes between the two formations. Toward the bottom the sandstone is medium-grained. The middle

[36] Jean Boussac, *op. cit.*, pp. 70 and 71.

and lower parts have a number of pebble conglomerate beds 2 inches to 6 inches thick. The pebbles are composed of sandstone, quartzite, and limestone, and are well rounded.

Limestone beds are intercalated in the sandstone. Some are regular and 6 inches to 12 inches thick; some are very irregular and amount to a layer of odd-shaped bodies, 6 inches to 24 inches in diameter. Some of these bodies are made up almost entirely of nummulites. Considerable sand forms the matrix in places between the nummulites.

The sandstone is generally not well cemented and is somewhat friable. It is massively bedded, some layers reaching 15 feet in thickness.

Characteristic fossils are: *Num. intermedius, vascus, bouillei; Eupatagus ornatus, Scutella subtetragona.* These indicate a Lattorfian (lower Oligocene) age.[37]

St. Martin siltstone.—The St. Martin siltstone is exposed continuously from Pointe Chambre d'Amour through the cliffs of Pointe St. Martin to the Miramar Hotel. One small outcrop just south of the Miramar Hotel and others in front of the Hotel du Palais (formerly the Villa Eugenie) reveal its continuation southward. The uppermost beds of the Biarritz sandstone, if projected to the Grand Plage are only about 75 feet stratigraphically below the lowermost siltstone outcrops. In this covered interval is the contact between the two formations. It may not be sharp but probably gradational because considerable fine sand is present in the siltstone in front of the Hotel du Palais, and the color is somewhat rusty instead of the ordinary blue-gray.

The St. Martin siltstone is named from Pointe St. Martin where the upper half of it is exposed (Figs. 4–5). The siltstone is dark gray to blue-gray and weathers to rusty tan. It may contain some very fine sand, and is not well cemented but contains, like the marls, appreciable calcium carbonate. The silt is in beds from 1 to 10 feet thick and shows a tendency to exfoliate. The beds of silt are separated from each other by beds of crystalline, dark gray limestone. The limestone beds are both regular and very irregular, and range from 6 to 18 inches in thickness. The formation is about 25 per cent limestone. The beds change in thickness conspicuously within short distances, some lensing out, some beginning, and the division of the formation into units on the basis of lithology did not seem feasible. It may be possible, however, to zone it faunally. It is about 450 feet thick.

Fossils occur abundantly in both the siltstone and the limestone and Boussac lists those given in Table II. These indicate a Rupelian and perhaps Chattian age (lower Oligocene), according to Boussac.

MIOCENE STRATA

Resting across the beveled edges of all the Tertiary and Cretaceous beds in a wide belt north of the Pyrenees in the southern part of the Aquitaine Basin are clays, peats, sands, and gravels of Miocene age.[38] As exposed along the cliffs south

[37] Jean Boussac, *op. cit.*, p. 89.

[38] *Carte Géologique de France, Bayonne 226,* 2nd Edition (1935).

of Biarritz they have filled former estuaries cut below a rather regular erosion surface in the Tertiary and Cretaceous strata. The Miocene fill extends a few feet below present sea-level, and farther inland it is possible that the drill in some locations might penetrate more than 200 feet of it.

PLEISTOCENE AND RECENT ALLUVIUM

Covering most of the Miocene clays and also masking to a great extent the bedrock, is a sand and gravel outwash from the Pyrenees. It is of Pleistocene age[39] and may also reach a thickness of 200 feet in places. Its sands are usually rusty. Undoubtedly most of the beach and dune sand north and south of Biarritz comes from it and the Miocene sands and gravels.

The sand of the sand plains of the Landes province of the central Aquitaine Basin is part of it, and the name "Sable des Landes" has come to be the formational designation. Because of the extensive blanket formed by the Miocene and Pleistocene alluvium in the Aquitaine Basin much of the prospecting for oil will have to be subsurface work, and preceded by geophysical prospecting and shallow test drilling.

STRUCTURE OF AQUITAINE BASIN

CRETACEOUS PIEDMONT

Between Biarritz and Tarbes is a rather wide Cretaceous belt that has been beveled by erosion to a surface of low relief. The surface was once a broad piedmont slope to the Pyrenees with a few hills rising 200 or 300 feet above it. It has since been elevated slightly and dissected by streams draining to the Golfe de Gascogne. The strata are chiefly of Upper Cretaceous age. The structures within the belt have not been mapped because of poor and scattered exposures, and the impression of complexity that one gets from seeing the outcrops. The shale, marl, and limestone beds are commonly at fairly steep angles in the outcrops and badly shattered.

Between Tarbes and Biarritz the Cretaceous zone is known as the Pre-Pyrenees or the north Pyrenees. It is the zone labeled "tightly folded Cretaceous" and the "zone of Keuper plugs" on the tectonic map (Fig. 6). It is generally believed that the Pre-Pyrenees were closely involved in the Pyrenees orogeny, but that the main thrust sheets lie at the south. They make up a foothill belt somewhat akin to the foothill structures of Alberta.

East of Tarbes the Cretaceous belt is narrower, and it appears to be part of the foothill province north of the Pre-Pyrenees (Fig. 6). This belt is described under the following headings, "Gentle Folds in the Nummulitique" and "Gas Fields near St. Gaudens."

ZONE OF TRIASSIC PLUGS

General characteristics.—In a zone stretching from Biarritz to Tarbes through Dax and Pau are a number of Keuper outcrops which have been interpreted as

[39] *Carte Géologique, op. cit.*

parts of plug-like intrusions. The Keuper shale with its beds of gypsum and salt and its numerous but small ophite plutons has bulged and intruded through the overlying Jurassic and Cretaceous strata in a number of places. It may even have broken through to the surface in one or two places and flowed outward so as to rest *on* the younger strata. This upward intruding and outward flowing type of structure is known to the French as an extravasation.

The intrusions may be dike-like in form or plug-like, and range up to a mile or more across. No one of them is known in detail because the Miocene and Pleistocene alluvium covers most of the surface. The Nummulitique is also younger than some of the Keuper extravasations and helps to mask them.

The quadrangle maps of the Carté Francais, particularly the Bayonne (266), the Orthez (227) and the Dax (215) sheets show the latest published detail. The geologists of the Societé Nationale des Pétroles d'Aquitaine have done additional work in the zone of plugs and undoubtedly have more information than is available in published form. Viennot's[40] geologic map has an insert that is particularly instructive about the distribution of the Keuper outcrops. The zone of Keuper plugs illustrated on the tectonic map of this report includes all of the Keuper exposures that the published maps just referred to show. Its shape follows the trends of fold axes and seems to demonstrate fairly well a small arcuate tectonic element north of the western Pyrenees.

The plugs are not the only structures in the zone of Keuper outcrops. The Cretaceous beds are folded but little is known of the fold axes and their relation to the plugs. One structure, known as the Tercis anticline just south of Dax, has nearly vertical flanks, and gives the impression of considerable compressional deformation in the zone of plugs.

Ilbarritz plug.—One plug worked out by the writer along the coast south of Biarritz is of significance because more detail is available about it than others, at least those that have been described. Its structural relations suggest the general nature of the other plugs in the zone.

The basic information along the coast opposite the towns of Ilbarritz and Bidart where the plug occurs is given in Figure 3. From this the interpretations for the cross section $B'B''$ (Fig. 4) and most of the geologic map (Fig. 5) have been made. Both a vertical-section interpretation and plan-view interpretation were made because it was felt that the one would be securer when checked and tied to the other. The map view is just as much an interpretation as the vertical section because in part it is under water and in part under an alluvial cover.

Geologists will be able to take the map and cross sections, and locate and check the exposures in the field with the exception, possibly, of these at Peyreblanque. There, so much detail is found in a small area that some explanation is necessary. In the first place, the writer recognizes an unconformity between the Peyreblanque limestone and the black and brown Jurassic limestones described

[40] P. Viennot, *op. cit.*

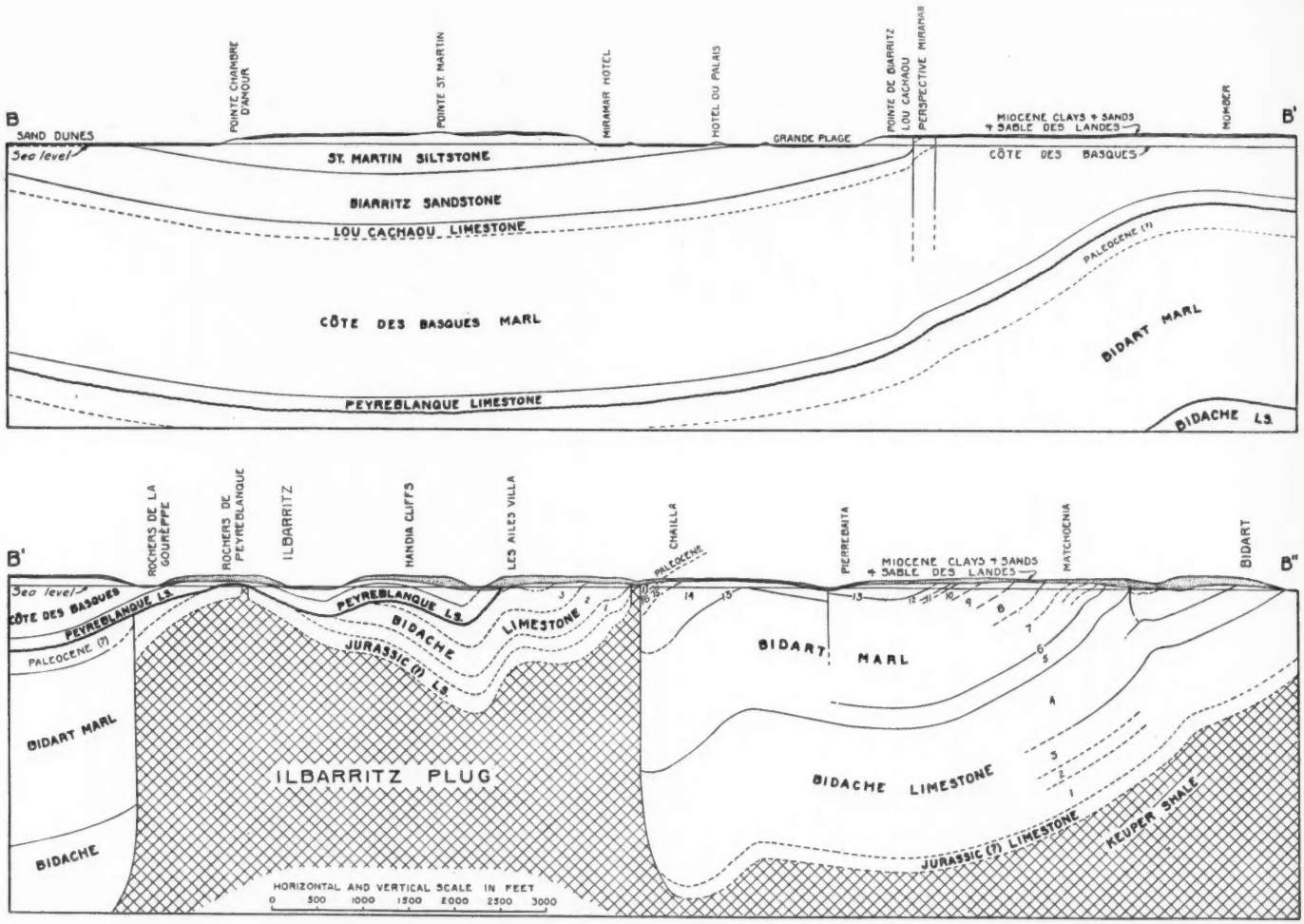

FIG. 4.—Cross section along coast from Biarritz to Bidart. See Figures 3 and 5.

in the previous section on stratigraphy. This unconformity may be seen in the several exposures immediately south of the two large rocks called specifically "Rochers de Peyreblanque." The break is a very irregular one and may be a surface with 200 feet of sharp relief. In spite of this irregularity the beds above and the beds below appear nearly parallel. This would indicate that both were upturned after the upper beds (Peyreblanque limestone) were deposited. The unconformity would not seem, therefore, to have been caused by sharp or local deformation, but by broad warping. This, however, is probably not the case, as is explained later.

The Danian beds that crop out as "reefs" offshore (No. 17 on map, Fig. 3) dip in toward the shore as if to project under the Jurassic limestones. This indicates a fault, and the structure is interpreted as shown in cross section AA' (Fig. 3).

The relation of the unconformity to the fault is of primary importance. The geologic pattern of the map at the Rochers de Peyreblanque suggests strongly that the Peyreblanque limestone extends out over the trace of the fault. If the Côte des Basques marl which overlies the Peyreblanque limestone is projected out to sea along strike, it also suggests strongly that the Tertiary beds blanket the fault (Fig. 5). Further evidence of the unconformity seems to be exhibited by the geologic pattern necessitated by the strike and dip of the exposures southwest of Lac de Mouriscot near the railroad tunnel and in clay quarries at the strike-and-dip symbol 35.

If the Peyreblanque limestone and overlying formations of the Nummulitique were deposited across the fault, then the fault and subsequent beveling by erosion occurred before the deposition of the Nummulitique. This is significant in relation to the theory of Keuper plug intrusion.

About a mile down the coast from the Rochers de Peyreblanque is a dike of Keuper shale. Its sides are fairly well exposed and both are nearly vertical (Figs. 3, 4, 5,). South of the dike is a continuous sequence of Upper Cretaceous (units 15 to 1) and Paleocene (units 17 to 16) strata. On the north is a series of Bidache limestone beds. The major problem concerns the position of the Bidache beds in the Bidache sequence. They are believed to be below any Bidache exposed along the coast between Bidart and San Jean de Luz, because there are no units in the section measured like them. But how far below is not known.

Cross section $B'B''$ (Fig. 4) shows that the Bidache beds north of the Keuper dike are upthrown perhaps 2,000 feet in relation to the Paleocene beds on the other side, and that the Keuper dike is along a fault. Also the Jurassic beds beneath the unconformity at Peyreblanque can be related to the Bidache beds, all of which are visualized as roof rocks of a major Keuper plug. A small mass of gypsiferous shales similar to those of the dike was exposed near the Jurassic outcrops at Peyreblanque when Boussac made his study in 1908, and a mass of ophite is still visible through the beach sands. The ophite is tantamount to an exposure of Keuper shale. These seem to be very small pipes or dikes of Keuper through the rather thin Jurassic limestone.

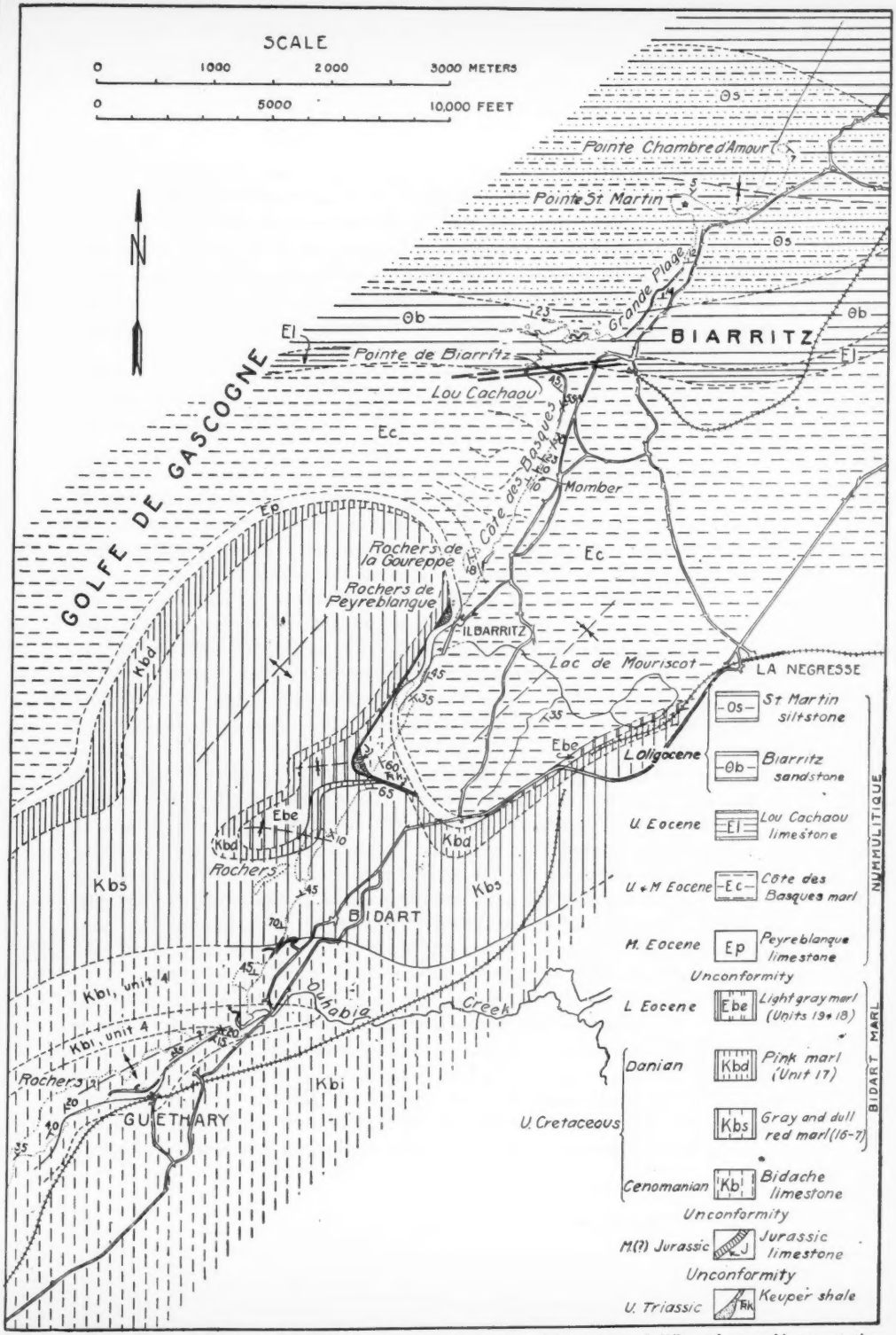

FIG. 5.—Interpretation of geology along Biarritz-Guethary coast. Dotted line is base of cliffs, and zone of interpretation extends under Golfe de Gascogne and under Miocene clays and gravels and Pleistocene Sable des Landes. Field mapping was done on Bayonne Nos. 3 and 7 sheets of Inst. Geographique National, Paris, which show geographic detail.

In the interpretation rendered of the Keuper plug of cross section $B'B''$ there is little place for a Lower Cretaceous sequence. It would be difficult to insert much of a thickness of Lower Cretaceous, if any at all, between the Jurassic and Upper Cretaceous. Since no Lower Cretaceous strata are known southward along the coast from Bidart, the belief that none exists in the immedate area of the Keuper plug of Ilbarritz is strengthened. The distribution map (Fig. 2) takes this conclusion into account. It is generally believed that no Lower Cretaceous extends northward much beyond the Adour River in the Aquitaine Basin.

It is also necessary, it seems, to terminate the plug on the north by a fault somewhere beneath the Peyreblanque limestone. The position of the fault is imaginary, as is also the relation of the Peyreblanque limestone to the Paleocene strata.

In regard to the north-south fault that separates the Danian strata from the Jurassic at Peyreblanque, the structure now appears to bound the plug on the west, as shown in cross section AA' (Fig. 3) and on the map (Fig. 5). The plug is, therefore, believed to be bounded by faults on three sides, and to resemble somewhat the plug of a watermelon, pushed up by an intrusion from within.

From the appearance of the unconformity the roof of the plug was the site of greatest erosion, and therefore, the locale of greatest hiatus. Erosion also trimmed the deformed beds on the sides of the plug, so that the Nummulitique is also believed to rest unconformably on the Paleocene. Cuvillier[41] states that the unconformity is probably widespread in the Aquitaine Basin and not local. This means, probably, that the time of Keuper plug intrusion was also one of widespread uplift and erosion.

As the beds of Paleocene and Danian age dip into the plug on the south and on the west, it appears that they were already folded before the Keuper intrusion occurred. It may be concluded therefore, that the first folding took place, at least in the Biarritz area, after the Paleocene, and that the Ilbarritz plug was intruded shortly thereafter. Rather extensive erosion removed about 2,000 feet of strata from the roof of the plug, and also beveled the surrounding Paleocene and Upper Cretaceous beds considerably. Then came the invasion of the Nummulitique sea and the deposition of nearly 3,000 feet of strata in it. After this, the second episode of folding occurred, because the Nummulitique is folded.

Some of the plugs in the general zone of Keuper plugs intrude the Nummulitique. The Oligocene part is known to rest unconformably on older strata in places with the Eocene part absent.[42] It is possible that the intrusion could have progressed in stages in some of the plugs. In fact, the Côte des Basques marl beds are vertical and badly shattered just back of the Jurassic exposure at Peyreblanque, and the small gypsiferous outcrop that Boussac mentioned, is through the Peyreblanque limestone. These observations suggest a second episode of in-

[41] Personal communication.

[42] Jean Cuvillier, oral communication.

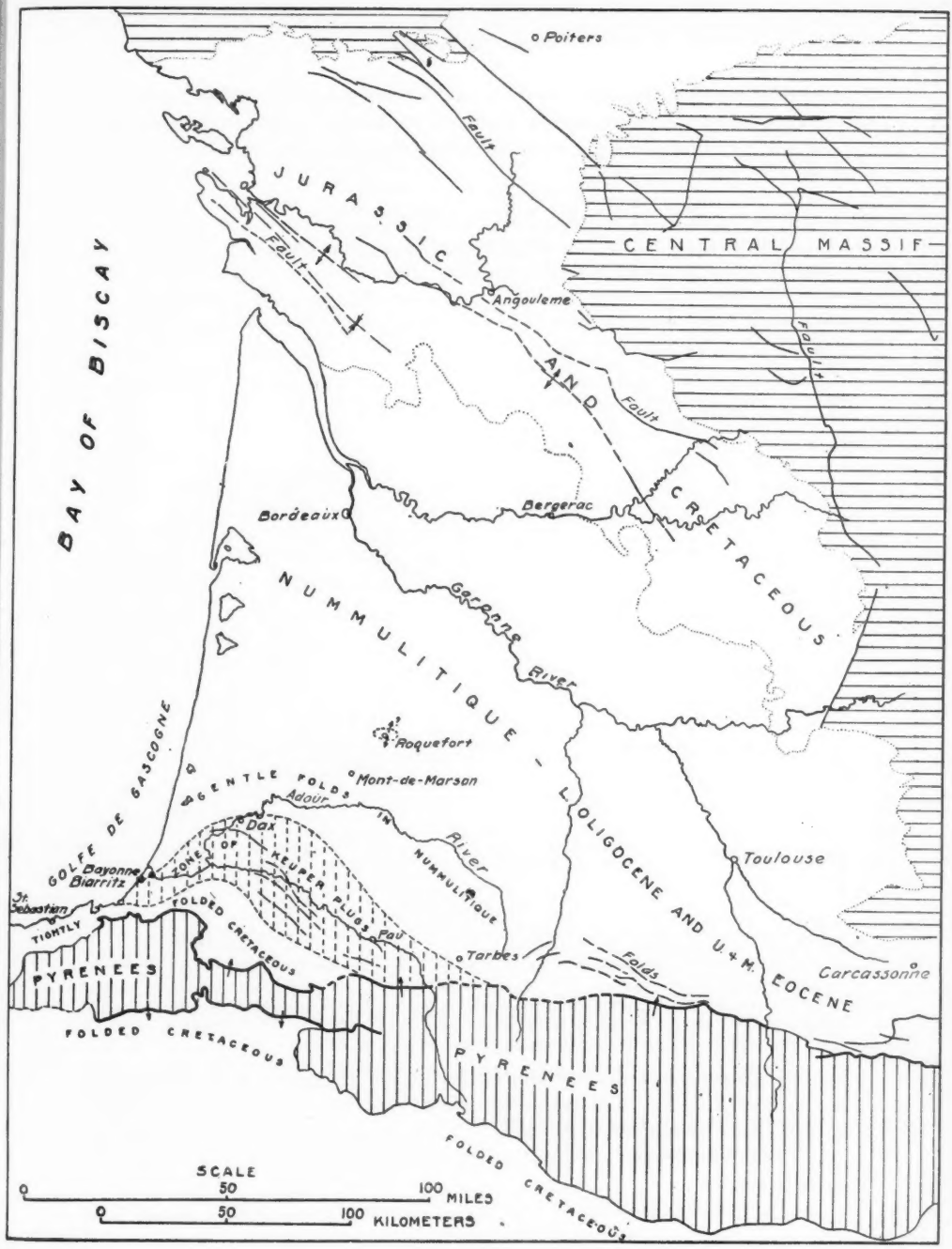

FIG. 6.—Tectonic map of Aquitaine Basin.

trusion for the Ilbarritz plug after the Côte des Basques marls had been deposited.

It is evident that the structures in the belt of Keuper plugs are complex, and they will be especially difficult to work out because of the extensive alluvial cover.

GENTLE FOLDS IN NUMMULITIQUE

In the Biarritz coastal area the Nummulitique beds are gently folded (Figs. 4 and 5). These gentle folds may be an index of the type of structure north of the

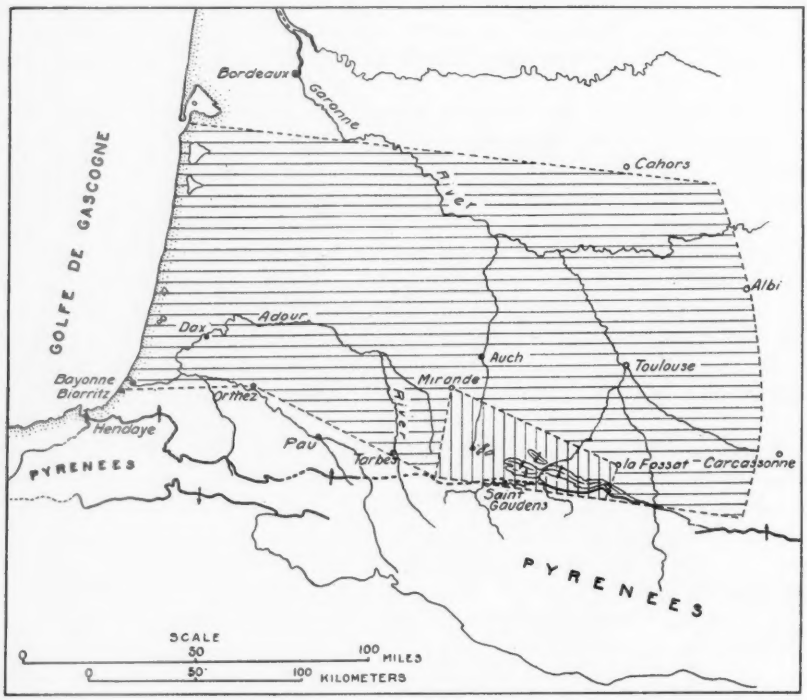

FIG. 7.—Map showing concessions in Aquitaine Basin. Horizontally ruled: Societé Nationale des Petroles d'Aquitaine. Vertically ruled: Regie Autonome des Petroles. Boundaries approximate, taken from map in *Oil Weekly* (March, 1945).

zone of Keuper plugs. Considerable Nummulitique is exposed in the area north of Dax but little has been published about the structure, if anything at all is known. The map pattern suggests fairly flat beds, so the gentle folds at Biarritz could well characterize a wide belt north of the zone of plugs and paralleling it in arcuate fashion.

If the tectonic map (Fig. 6) is correct, this belt of gentle folds connects with

the folds of the gas fields near St. Gaudens. There the folds are fairly sharp and complicated by faults, so it may be that the folds from Biarritz eastward gradually take on a sharper and more complicated aspect.

GAS FIELD NEAR ST. GAUDENS

Gas was discovered in commercial quantities in July, 1939, on the St. Marcet structure just north of St. Gaudens (Figs. 7 and 8). The construction of a 60-mile

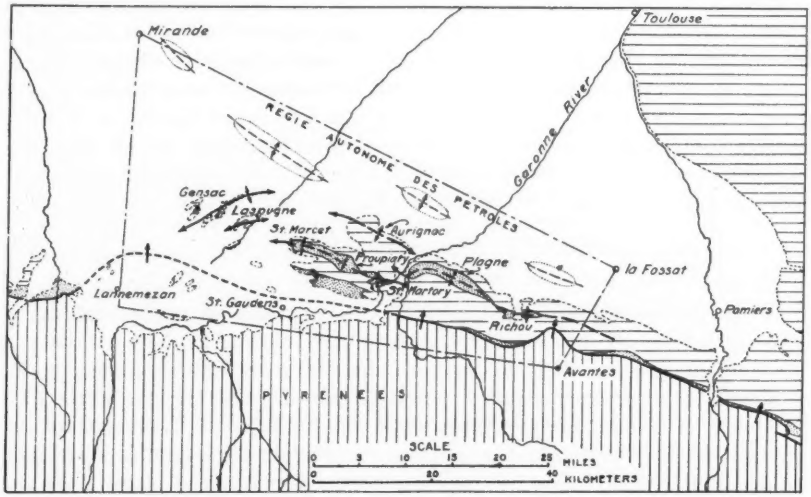

FIG. 8.—Map showing concession of Regie Autonome des Petroles, and gas fields in it. Stippled are Upper Cretaceous with exception of Maestrichtian. Horizontally ruled areas are Maestrichtian and Nummultique. Blank area is covered by alluvium. Vertically ruled area is complicated thrust structure of Pyrenees. Structures indicated by dotted lines have been located by geographical prospecting. Taken from Leon Bartrand, Pl. II, "Pyrenees Centrales et Orientales," Bull. 118, Tome 17 (1906), and *Oil Weekly* (March, 1945).

6-inch natural-gas line to Toulouse in November, 1942, gave the field its first outlet, and development started. By March, 1945, 13 wells had been drilled by American rotary equipment and ten of them were producers. The daily production at that time was 8 million cubic feet of gas and 20 barrels of 31 gravity oil.[43] Another 6-inch pipe line is being laid to Tarbes. The gas is wet and an absorption plant obtains 8 gallons of distillate from 1,000 cubic feet of gas. The plant has a capacity of 10 million cubic feet of gas.

During the occupation the Germans started three wells but never completed them. The French are pressing exploration vigorously at the time of the present

[43] Weldon Hill, "New Field in France being Developed," *Oil Weekly* (May 28, 1945).

writing. The 600,000 acre concession called the Regie Autonome des Petroles is entirely owned and controlled by the French Government. A larger concession that covers much of the Aquitaine Basin, the Societé Nationale des Petroles d'Aquitaine, is owned, 55 per cent by the French Government and 45 per cent by private interests (Fig. 7).

Both surface geological mapping and geophysical prospecting have been pursued in the area of the gas fields and a number of structures are known and await drilling (Fig. 8).

Production comes from depths of 4,500 to 5,500 feet in beds of dolomite of Jurassic age. Beds of Danian and Senonian age occur at the surface and form a simple anticline whose flanks dip about 30°. A careful charting of dips by Schneegans and Michel[44] in surveyed and cored wells has led them to interpret a Keuper plug-like structure at depth. The Upper Cretaceous appears to rest unconformably on the Jurassic dolomite and small marginal thrusts have accompanied the plug intrusion. The wells have been drilled generally to about 6,800 feet and one is shown bottomed at 8,875 feet.

APPRAISAL OF OIL AND GAS POSSIBILITIES

POSSIBLE SOURCE ROCKS

Figure 2 shows the Jurassic, Lower and Upper Cretaceous, and Eocene strata to occur extensively in the Aquitaine Basin. Of these the Lower Cretaceous is probably absent north of the Adour River, and the Eocene thin or missing on the anticlines. It seems fairly certain, therefore, that except for the area of the Pre-Pyrenees and zone of Keuper plugs, that the Jurassic and Upper Cretaceous are the strata in which oil and gas are likely to occur in the Aquitaine Basin. The unfavorable Triassic formations lie beneath the Jurassic, and below these the ancient crystallines of the Hercynian orogeny.

In the south and southwest outcrops of the Aquitaine Basin the Jurassic and Cretaceous beds are preponderantly marl, and medium to light gray in color. Limestones where present are also generally gray. There is a general paucity of black shales and brown limestones. The only rock observed that contains oil is a hard compact limestone in a quarry at Orthez. It had been fractured and the fractures filled with porous calcite, which in turn was impregnated with an asphaltic oil, as if the oil had migrated upward from a source rock below. The limestone is Senonian in age.[45]

The marl is massive and fairly devoid of megascopic pore spaces. It appears to contain very little organic matter. In consideration of marl as a source or container of oil in the United States the writer finds the occurrences very few. Marl may serve better as a cap rock than as a source or reservoir rock. It seems necessary to conclude, therefore, that the marly nature of the sedimentary rocks of the

[44] M. M. Schneegans et Michel, "Cross-Section of the St. Marcet Anticline" (not yet published).

[45] Jean Cuvillier, personal communication.

Aquitaine Basin, particularly of the Cretaceous, is not very promising for oil and gas production. It rather narrows the quest for oil to the Jurassic limestones, and especially to those immediately below the Upper Cretaceous, because there, an erosion surface exists, and with it, presumably, porosity. Some hope, of course, can be entertained for oil in the marl sequences, because oil has been found unexpectedly in so many different kinds of rock that none can be condemned with assurance until tested by the drill. Also the Upper Cretaceous may be of a limestone facies under the Nummulitique in the basin north of the Adour River. As indicated under the section on stratigraphy the Upper Cretaceous along the northern edge of the basin consists of limestone, sandstone, and lignitic clays. There are reefs of rudistids in some of the limestones. Only the drill can finally determine the possibilities of the Upper Cretaceous under the Tertiary cover.

LOCATION OF FAVORABLE STRUCTURES

Triassic plugs.—The occurrence of oil in beds over, on the side of, and partly under salt plugs is well known and, therefore, the Keuper plugs of the Aquitaine Basin may be viewed as favorable structures. Production over all those plugs that are exposed is impossible because the roof is gone. Oil accumulations may be present on the sides but the exposures are so poor that detail of the structure is almost impossible to obtain, and therefore great uncertainty will exist in the location of wells for side production. Geophysical prospecting around the plugs might help define them.

The anticlines in the zone of plugs are sharp and accompanied with faults, and the impression is obtained that perhaps most of the structures will be too sharp for oil, but perhaps if wells can be located correctly gas might be obtained.

North of zone of Triassic plugs.—Gentle folds are probably present north of the Biarritz-Dax-Tarbes zone of plugs and merge with the sharper folds of the St. Gaudens area. The gentle folds seem to be the most promising structures in the basin. There is more probability there, than farther south, that the Upper Cretaceous strata is limestone, and the Jurassic should lie at the easily attainable depths of 1,500 to 2,500 feet. However, since the area is almost completely blanketed by sand it will be necessary to locate the structures by geophysical prospecting or shallow test drilling.

Test drilling should be successful because all of the strata down to the Jurassic are full of microfossils, and correlations from well to well could easily be made.

The ability to locate structures easily and reasonably well, and the shallow depths to which wells will have to be drilled should make it feasible to explore a number of structures before interest lags in the oil and gas prospects of the Aquitaine Basin. If this basin were present in the United States it would have been exhaustively explored long ago.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 9 (SEPTEMBER, 1946), PP. 1546-1584, 15 FIGS.

STATUS OF GERMAN OIL FIELDS[1]

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ABSTRACT

The most active period in Germany's 85 years of oil-field development was the decade that ended with the close of World War II. Twenty-eight oil fields were discovered during that period and 62 per cent of Germany's total cumulative production obtained. About half of the new fields were found in the old Hannover producing district, from which has come more than three-fourths of all the oil produced in the country. The oil from the earliest of these new fields together with that obtained in extensions of the old Nienhagen field resulted in the annual crude production being more than doubled between 1935 and 1940. In the latter year an all-time peak of 7,393,309 barrels was reached. In spite of the discovery of 11 fields since, the production declined after 1940 and was only 5,053,552 barrels in 1944 and 3,838,709 barrels in 1945.

Most of Germany's crude oil comes from Lower Cretaceous and Jurassic formations on the flanks of salt structures which are the result of a combination of tangential folding, occurring during the late Jurassic and Cretaceous, and the upthrusting of Upper Permian salt beds. The oil in the Central Hannover district is in most places confined to narrow belts of tilted strata on the flanks of the salt structures, the thin producing sands being sealed in by uncomformities and faults.

Only one important field—Reitbrook—has been found on the crest of the many deep-seated domes that have been discovered by geophysical prospecting in the region north and northwest of the Central Hannover district. It was formerly believed that large production would be obtained from the Hannover oil sands on the crest and flanks of these domes. Many of them have as yet not been adequately tested, but of the two score or so drilled only four have yielded oil chiefly from Upper Cretaceous chalks. The poor showing made by these domes evidently is due to the absence from the region of the Lower Cretaceous and Jurassic oil-bearing formations. The Pompeckj uplift, from which these formations were eroded, extends over a much greater area than was formerly recognized.

Another disappointing development has been the failure to find important new production in the Middle Zechstein dolomites in central Germany. The discovery of oil from these dolomites at Volkenroda in the Thuringian basin in 1930 has led to no other commercial field being found in the region.

These unsuccessful developments have been offset to some degree by the new discoveries at Heide in Schleswig-Holstein and near the Dutch border in western Germany. In the Heide fields oil is produced from Middle Zechstein dolomitic limestones and a pre-Neocomian scree breccia on the west flank of an elongate salt structure with a core of Rotliegend salt-bearing strata.

The three fields discovered near the Dutch border in 1942 and 1943 produce from Lower Cretaceous sands and shell beds. They are situated on low folds unrelated to salt tectonics. These new developments, together with the possibility of discovering deeper sands on the flanks of salt structures, and the search for gentle folds between the salt structures, offer the best prospects of new discoveries. The Munich basin probably is the only region outside of the producing districts that justifies exploratory work.

INTRODUCTION

LOCATION AND YIELD

During the past 85 years, 33 oil fields have been discovered in Germany, all excepting three of which are situated in the North German Plain in northwest Germany (Fig. 1). One minor field had a small production in the Thuringian basin of central Germany between 1930 and 1938 and two small fields have been discovered since 1934 in the Rhine Valley of south Germany. The fields in the North German Plain may be grouped into the following districts: Schleswig-Holstein, Oldenburg, West Hannover, North Hannover, and Central Hannover. The fields in the first three districts represent important new discoveries made outside of the old producing districts chiefly during World War II.

[1] Manuscript received, April 13, 1946.

[2] Consulting geologist.

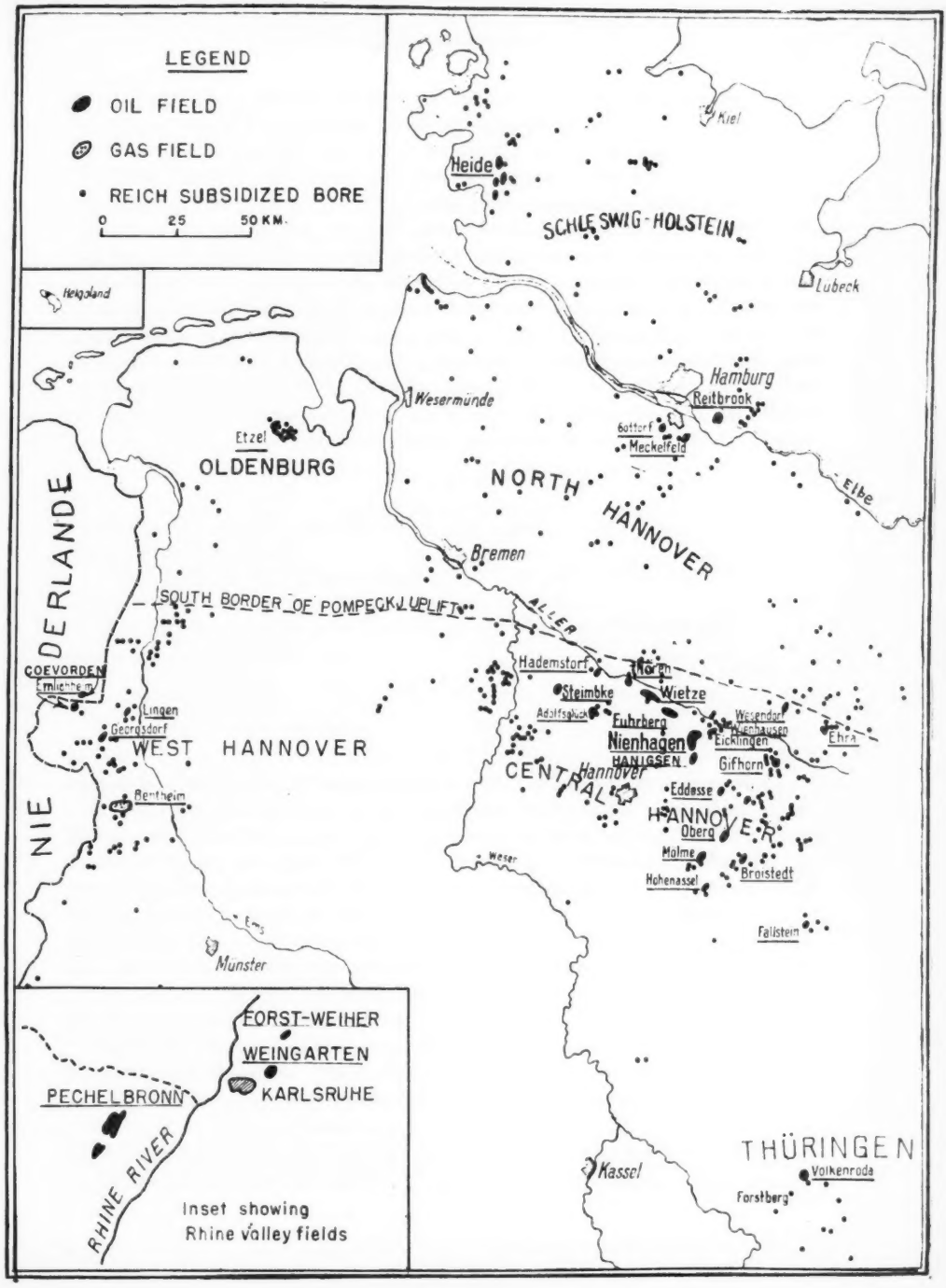


FIG. 1.—German oil fields.

To the end of 1945 the German fields have yielded around 73,523,335 barrels[3] of oil, 60 per cent of which has been produced since 1934. This comparatively large recent production may be attributed to the Nazi Government's efforts to increase its crude-oil supplies in the 5 years previous to the outbreak of World War II. As a result of extensive geophysical prospecting and Government subsidized exploration drilling, production was increased from 2,991,534 barrels in 1935 to 7,393,309 barrels in 1940. With a curtailment of exploratory work and the shift of drilling equipment to Austria and other eastern European fields, production declined during the following years. In 1944 it was only 5,053,552 barrels. During the invasion period, April and May 1945, the production declined to one third of the normal after which it began to pick up and by September, 1945, was back to its average pre-invasion production of around 13,000 barrels daily (Table III). 1945 production, because of the invasion shut-down, was 3,838,709 barrels. 1946 production will be around 4,500,000 barrels.

TABLE I

OIL PRODUCTION BY DISTRICTS

Oil-Producing District	*Number of Fields*	*Cumulative Production in Metric Tons to End of 1945*
Schleswig-Holstein	5	1,029,504
Oldenburg	1	7,981
West Hannover	3	62,028
North Hannover	3	1,096,848
Central Hannover	18	8,128,530
Thuringian basin	1	80,984
Rhine Valley	2	93,074

Eighty-eight per cent of the oil has come from 3 fields—Nienhagen and Wietze in the Central Hannover district and Reitbrook in the North Hannover district. Of these, Nienhagen is by far the most important, having yielded 38 per cent of all oil produced in Germany to the end of 1945. Although it is one of the oldest fields and has produced oil since 1860, it did not reach its peak annual production of 2,507,360 barrels until 1938. Wietze, another old field, reached its peak in 1908 with 773,752 barrels. Since then its production has declined and was only 229,040 barrels in 1944. In 1917 oil mining was introduced at Wietze and has accounted for a considerable part of its subsequent yield. Reitbrook, the third largest field in total oil produced, began production in 1937 and reached its peak of 2,500,554 barrels in 1940 when it was the largest producing field in Germany. Since then it has declined rapidly and produced only 251,433 barrels in 1944, being outranked in that year by Nienhagen, Hänigsen, Fuhrberg, Rodewald, and the Heide

[3] Figures of production expressed in barrels have been obtained by converting metric tons into barrels by multiplying the former by 7. Actually the conversion factor varies from 6.4 to 7.4 in the different fields and almost as much in different sands of individual fields. For accuracy the production data in all tables are given in metric tons.

fields. The afore mentioned fields together with Oberg, Oelheim and Eichlingen are the only fields whose cumulative production exceeds one million barrels.

NEW FIELDS

From 1935 to 1944, inclusive, 28 oil fields were discovered in Germany which to the end of 1945 have had a total cumulative production of more than 26,000,000 barrels. Thirteen of these are situated in the Central Hannover district, 5 in Schleswig-Holstein, 1 in the Oldenburg district, 3 near the Dutch border in the West Hannover district, and 2 in the Rhine Valley district. The largest of these new fields is Reitbrook which to the end of 1945 had produced 10 per cent of Germany's total output. Other new fields with a fairly large cumulative yield are the Heide group of fields in Schleswig-Holstein, and Rodewald and Fuhrberg in the Central Hannover district. Fields that were discovered too recently to rate very high in cumulative production but which show promise of further expansion are Wesendorf and Hohenassel, near Hannover, and the Dutch border fields.

A gas field was actively developed near Bentheim, south of Dalum, during the war.

The most important discoveries from the viewpoint of future developments are the Heide and Dutch border fields.

Table II summarizes the information on the production of the oil fields developed during the past 10 years.

Producing Formations

Oil in the German fields is obtained from 25 or more sands ranging in age from Permian to Oligocene. Slightly more than half of the oil comes from Lower Cretaceous Wealden and Valendis sands. Senonian chalky limestones of Upper Cretaceous age have yielded approximately 15 per cent of the oil most of which is produced from the Reitbrook field. About the same volume of oil has come from calcareous sandstones and limestones in the Dogger and Malm of the Middle and Upper Jurassic. The Middle Zechstein dolomites and limestones of Permian age and the Rhaetic sandstones of Upper Triassic age have each yielded nearly 10 per cent of the total production. Some oil has been obtained from Tertiary sands in the Rhine Valley fields and at Reitbrook.

Data about the character, thickness, porosity, and distribution of the producing sands are given in the following summary.

Oligocene.—Upper, middle, and lower Oligocene sands yield most of the oil in the Rhine Valley fields. The producing sands are lenticular, fine-grained, clayey and of low porosity and small yield. Sands of the same age are the chief producing formations in the Pechelbronn fields on the west side of the Rhine.

A lower Oligocene sand formerly produced gas at Neuengamme on the southeast margin of the Reitbrook field. This sand is 17 meters thick and has a porosity of 25 per cent.

TABLE II

GERMAN FIELDS DISCOVERED DURING PERIOD 1935–1944

District and Field	*Date of Discovery*	*1944 Production in Metric Tons*	*Cumulative Production End of 1945, Metric Tons*	*Producing Sands*
Central Hannover district				
Gifhorn	1935	3,036	34,856	Wealden
Moelme and Feldbergen	1935	14,383	113,764	Rhaet, Wealden, Malm
Fallstein	1935–37	None	1,872	Middle Zechstein
Rodewald	1936	53,533	295,808	Wealden, Serpulit, Cornbrash
Broistedt	1937	2,570	17,474	Wealden
Eichlingen	1937	19,641	201,236	Wealden, Valendis
Fuhrberg	1939	60,693	238,142	Cornbrash
Ehra	1939	385	7,341	Dogger beta
Hademstorf	1941	10,134	20,712	Wealden
Hambühren	1941	2,222	5,802	Cornbrash, Senonian
Thören	1941	22,398	76,522	Wealden, Cornbrash
Wesendorf	1943	34,271	90,589	Dogger beta
Hohenassel	1943	14,873	47,555	Malm
North Hannover district				
Reitbrook	1937	35,919	1,053,530	Senonian, Eocene
Meckelfeld	1938	4,531	38,335	Senonian, Lower Cret.
Schleswig-Holstein				
Hölle	1935–40	125,817	1,029,504	Cenoman. Rotliegend
Lieth	1937			Middle Zechstein
Rickelshof	1939			Mid. Zech., pre-Neocomian and breccia, Neocomian
Meldorf	1941			Pre-Neocomian breccia
Hemmingstedt	1944			Pre-Neocomian breccia
Oldenburg district				
Etzel	1942	3,139	7,951	Dogger epsilon, Senonian, Eocene
West Hannover district				
Lingen	1942	19,148	41,675	Valendis, Wealden
Georgsdorf	1944	3,012	12,303	Valendis
Emlichheim	1944	3,017	8,050	Valendis
Rhine Valley district				
Forst-Weiher	1935	5,322	63,498	Oligocene, Keuper, Dogger beta
Weingarten	1936	3,070	29,911	Oligocene

Eocene.—A lower Eocene sand has yielded a little oil in a few wells at Reitbrook. Gas is obtained from an upper Eocene sand in the same field. An Eocene sand is impregnated with heavy asphaltic oil in the Etzel field. A good showing of oil was found also in the Eocene at Sottorf.

UPPER CRETACEOUS

Senonian.—Porous glauconitic marly limestones of probable Maestrichtian age occupy the upper part of the Senonian chalks in a narrow belt between Hamburg and Bremen and are known as the Reitbrook beds. They yield the bulk of the oil in the Reitbrook, Meckelfeld, and Sottorf fields near Hamburg. At Reit-

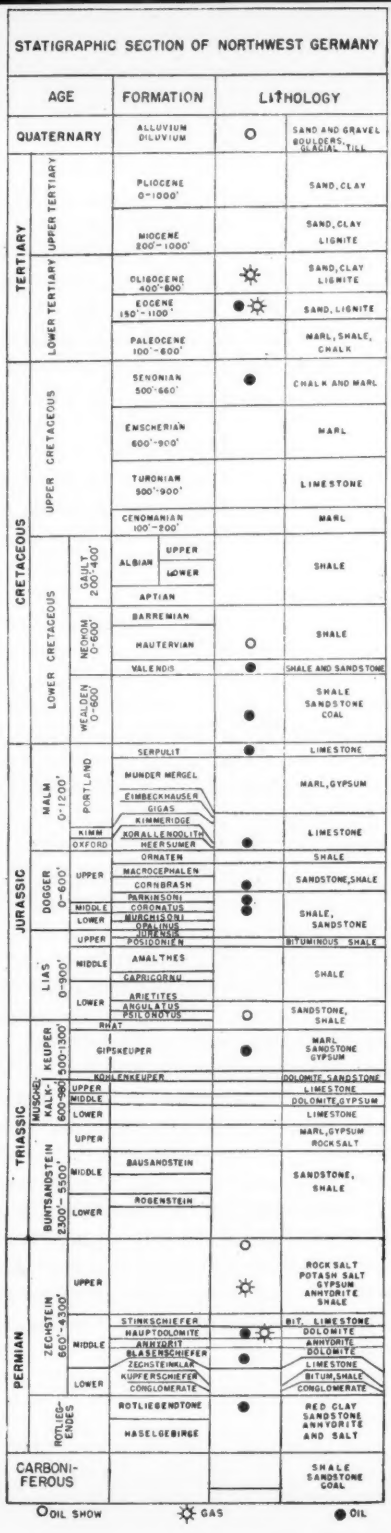


FIG. 2.—Generalized stratigraphic section of northwest Germany showing producing formations.

brook the producing zone is 65 meters thick and has a porosity of 25 per cent but a permeability of only 2 millidarcys. Its productivity is due to fissuring associated with faulting. Some oil has been obtained from the Upper Senonian in the Wietze, Hambühren, Etzel, and Heide fields. In the Heide fields the so-called oil chalks, Senonian and Turonian in age, were formerly mined and during the war a little oil was produced from them in two wells just west of Heide.

Cenomanian.—A little oil was produced from Cenomanian fissured limestones in the Hölle field near Heide during the period of 1935 to 1940.

LOWER CRETACEOUS

Neocomian.—Some oil has been obtained from fine sand partings in brown gray shale of Neocomian age in the Rickelshof field west of Heide. A little production has been obtained from the Hauterivian division of the Neocomian at Eichlingen. Good showings of oil in Neocomian sands were obtained in the Meckelfeld and Wesendorf fields.

Valendis.—The Valendis is the second largest producing formation in the German fields. It is one of the important producing formations in the major fields of Nienhagen, Hänigsen, and Eichlingen near Hannover. The producing sand in these fields is 10–30 meters thick and varies from a coarse- to fine-grained sand of variable porosity and permeability. The Valendis is also the principal producing formation in the Dutch border fields of Emlichheim, Georgsdorf, and Lingen and the Coevorden field lying across the border in Holland. At Emlichheim the sand is a medium- to coarse-grained loose sand with a porosity of 25–39 per cent and a fairly high permeability. The Valendis sand in the Georgsdorf field is 35 meters thick and has a low porosity and permeability with production depending on fissuring and faulting. In the Lingen field oil is obtained from two Valendis sands with a porosity of 12–15 per cent and low permeability.

Wealden.—The Wealden sands are the most important in the German fields and are best developed in the eastern part of the Hannover basin where they are important producers in the Nienhagen, Hänigsen, Eichlingen, Gifhorn, Oelheim, Oberg, Mölme, Broistedt, Thören, Wietze, Hademsdorf, and Rodewald fields.

In the Nienhagen and Hänigsen fields the Wealden is a coarse- to fine-grained soft sand 10–15 meters thick which pinches out updip due to the Valendis transgression. It has a porosity of 25–30 per cent locally reduced by calcareous cement. In the fields farther eastward (Gifhorn, Oberg, Oelheim, Mölme, and Broistedt) the chief Wealden production comes from two or more medium- to fine-grained Fühse sandstones 5–15 meters thick in the upper part of the Wealden. West of Nienhagen oil is found in the Wealden in the Wietze, Thören, Hademsdorf, and Rodewald fields. The producing beds are brackish-water sands interbedded with shale. At Weitze four Wealden sands have a total thickness of 80 meters. In the other three fields the Wealden producing beds are several thin oil sands 1 to 2.5 meters thick with a total thickness of 5 to 15 meters.

The Wealden formation attains a considerable thickness in the West Hann-

over district but consists chiefly of clays and bituminous shales. In the Lingen field the Wealden shales contain 20–30 bands of Lumachella shell beds up to 0.3 meters thick with a porosity of 12–15 per cent which yield most of the oil. In the other Dutch border fields the Wealden consists of shales and marly limestone with no reservoir capacity. North of the Hannover basin[4] the Wealden and Valendis are absent due to uplift and erosion in Jurassic and Lower Cretaceous time.

A pre-Neocomian scree breccia which is an important producing formation in the Rickelshof Hemmingstedt and Meldorf fields near Heide may be of Wealden age. This sedimentary breccia varies greatly in thickness and consists of Rotliegend red sandy marl, Zechstein porous limestone, Keuper variegated shale, and Triassic limestone. It has been found only in small pockets lying on the eroded surface of Upper Zechstein beds on the west flank of the Heide Rotliegend salt structure.

JURASSIC

MALM

The Malm appears to be absent from all of the North German Plain except the Hannover basin and there it is lacking in many places on the upper flanks of salt structures due to transgressing Lower Cretaceous formations. Where present the Malm consists chiefly of marl and limestone which are ordinarily too compact to yield oil. The only important production is found in the Hohenassel, Mölme, and Rodewald fields where secondary porosity has been developed. In the first two named fields a porous oölitic Korallenoölith limestone 15 to 20 meters thick is an important producer. In the Rodewald field about one-third of the oil comes from a Serpulit limestone in which *Serpula* tubes give the limestone its porosity.

DOGGER

The Middle Jurassic Dogger is well developed in the Hannover basin, and is an important producer in several fields in the Central Hannover district. It is well developed in the West Hannover district but reservoir rocks as yet have not been found there. It has not been encountered in the region occupied by the Pompeckj uplift except at Etzel. The Dogger sands are derived from this uplift. The chief Dogger reservoir rocks are in the Cornbrash, Dogger epsilon, and Dogger beta members.

Cornbrash.—The Cornbrash yields oil in the Thören, Wietze, Fuhrberg, Hambühren, Rodewald, and Nienhagen fields. In all except the two last named fields there are two producing sands, an upper calcareous sandstone 10–20 meters thick and a lower Lumachella limestone 10–15 meters thick. In the Rodewald and Nienhagen fields the producing formation is a calcareous sandstone or grit 10–25 meters thick. The porosity of the Cornbrash varies with its degree of calcareous cementation.

[4] The Hannover basin occupies the area south of the Pompeckj uplift (Fig. 1).

TABLE III

CRUDE OIL PRODUCTION—GERMANY—1945 AND 3 MONTHS 1946

(In Metric Tons)

Field	*January*	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*	*Year's Total*	*1946 January*	*1946 February*	*1946 March*
Brostedt	178	150	144	—	—	176	83	185	189	179	140	189	1,613	217	195	221
Calberlah	—	—	3	—	—	3	42	41	6	18	18	21	152	8	9	36
Eddesse-Ölheim	333	276	289	59	104	309	270	227	233	250	236	278	2,864	277	258	289
Ehra	10	30	4	—	—	—	—	—	—	—	—	—	44	—	—	—
Eichlingen-Weinhausen	1,465	1,247	1,419	283	1,068	1,198	1,249	1,168	1,117	1,135	1,091	1,045	13,485	1,217	1,065	1,245
Emlicheim	850	646	504	—	—	—	—	—	27	355	1,216	1,435	5,033	1,098	623	1,349
Etzel	370	51	64	—	—	—	—	—	117	402	437	414	1,855	409	305	376
Fuhrberg-Hambühren	5,150	4,770	3,332	486	—	—	—	1,907	4,582	4,702	4,425	4,420	33,864	4,586	4,275	4,514
Georgsdorf	782	748	496	—	—	—	—	780	1,580	1,658	1,522	1,725	9,291	1,535	1,238	1,476
Gifhorn	292	234	185	118	—	—	—	12	256	278	252	81	1,708	160	98	120
Hademstorf	585	485	211	—	—	—	234	276	558	566	566	627	4,108	648	512	434[a]
Hänigsen	3,865	3,401	3,562	759	2,319	2,435	2,800	3,382	3,031	3,544	3,061	3,011	35,170	2,915	2,649	7,346
Heide-Meldorf	10,591	9,255	9,937	8,545	2,356	6,078	6,325	7,411	7,392	7,785	7,959	7,225	90,859	6,837	6,610	
Hohenassel	3,582	3,297	2,247	342	429	123	1,254	4,332	4,119	3,813	3,810	4,186	31,534	3,888	4,647	5,015
Lingen-Dalum	2,166	1,960	1,474	—	—	—	—	—	2,952	2,316	2,771	2,642	16,281	2,604	2,360	2,981
Meckelfeld	384	376	258	88	—	—	75	163	131	232	296	322	2,325	268	200	126
Mölme	1,068	919	888	239	330	665	651	644	776	616	555	415	7,776	446	504	690
Nienhagen	13,616	12,527	12,808	2,428	8,126	8,730	12,298	12,368	12,142	12,042	11,837	11,401	130,323	11,910	9,009	15,101[a]
Oberg	940	724	854	22	568	605	638	466	700	841	943	938	8,239	971	820	945
Reitbrook	3,088	3,095	3,519	2,347	2,123	2,636	2,868	2,814	3,003	3,146	2,840	2,989	34,468	2,820	2,683	2,992
Sottorf	2	8	—	—	—	—	—	—	—	—	—	—	10	—	—	—
Steimbke-Rodewald[a]	1,888	2,610	3,264	—	—	—	1,420	2,291	1,706	3,805	3,712	2,876	23,572	2,787	3,246	4,023
Thören	1,644	1,701	1,939	330	342	205	221	1,150	2,027	2,366	1,699	2,327	15,951	1,907	1,705	1,743
Wietze	2,591	2,397	2,542	539	963	963	1,046	1,084	1,751	1,995	2,069	1,960	19,900	1,915	1,772	1,929
Wesendorf	4,847	3,912	2,700	1,102	1,811	4,993	5,574	5,177	5,010	5,350	5,400	5,596	51,472[b]	4,195	4,142	3,754
Weingarten			No information. Estimated at 1,869 tons							180	228	223	2,500[b]	219	129	213
Forst-Weiher			No information. Estimated at 3,008 tons							350	290	352	4,000[b]	230	319	351
Total	60,287	54,819	52,643	17,687	20,539	29,119	37,048	45,878	53,405	58,014	57,373	56,698	548,387	54,067	49,373	57,276

[a] Hänigsen included in Nienhagen.
[b] Estimated.
Source: Major A. E. Gunther, chief geologist in charge of oil-field investigations at Celle in British-occupied zone.

Dogger epsilon (*parkinsoni*).—A lower Dogger limestone breccia, encountered locally on the northwest flank of the Etzel structure, has yielded oil in two wells.

Dogger beta (*murchisoni*).—This lower Dogger member yields oil in the Ehra, Wesendorf, and Oberg fields. In the Ehra field oil is found in two sands, each 3 meters thick, with a porosity of 10–38 per cent. At Wesendorf the single producing member is 3–12 meters thick and has an average porosity of 23 per cent and a permeability of 600 millidarcys. Some oil is also obtained from a lower Dogger sandstone in the Rhine Valley of Forst-Weiher field.

The Dogger production in the Oberg field is confined to the nose of the structure and is obtained from a fine-grained sandstone 6 meters thick with a porosity of 12–22 per cent.

LIAS

Sandstones are found in the lower Lias in the region east of the Weser River but most of them appear too compact to act as reservoir rocks although some oil has been obtained from them in the Nienhagen and Oelheim fields and they contain oil showings in the Mölme, Hänigsen, Hohenassel fields.

TRIASSIC

No oil has been found in the thick Triassic formations except in the Keuper. The principal production comes from Rhaetic sandstones and the Schilfsanstein of the Gipskeuper in the region east of the Weser.

Rhaet.—Sandstones occur at several horizons in the Rhaet. They are in most places fine-grained sandstones of fair porosity and low permeability. They have a thickness up to 60 meters in the east but thin out toward the west. A middle Rhaetic sandstone is an important producer in the Oelheim, Mölme, Wietze, and Nienhagen fields and yields good showing in the Führbergs and Hänigsen fields.

Schilfsandstein.—This middle Keuper sandstone is an important producer at Dannhorst in the Nienhagen field and is the main producing sand in the Rhine Valley Weiher field.

PERMIAN

Upper Zechstein.—The thick series of shale, anhydrite, dolomite, and salt comprising the Upper Zechstein has yielded no commercial oil production although showings of oil have been obtained in the Gipshut or cap rock in a few fields. A commercial gas field producing from the Upper Zechstein Plattendolomit was developed during the war on the Bentheim fold and gas under high pressure has been encountered in fractured Zechstein anhydrite beds in two Reitbrook wells.

Middle Zechstein.—Oil has been obtained from the Middle Zechstein Hauptdolomit at Fallstein at the eastern end of the Hannover basin, at Volkenroda in the Thuringian basin, and in the Hauptdolomit and Blasenschiefer in the Leith and Rickelshof fields near Heide. The Hauptdolomit at Fallstein and Volkenroda

is a compact dolomite with low porosity and permeability. Its reservoir capacity at Volkenroda is due chiefly to the presence of numerous fissures in a zone of faulting. The Middle Zechstein in the Heide fields is productive chiefly because of cavities resulting from the solution weathering of anhydrite pebbles or nodules in dolomitic limestone during a period of pre-Neocomian erosion. Some of the first wells from these formations yielded more than 1,000 barrels daily.

Rotliegend.—A little oil was formerly obtained in the Hölle field from sandy marls in the Banderschiefer member near the top of the Rotliegend.

Structure

The structure of most of the German oil fields is due to a combination of salt

Fig. 3.—Permian salt basins. (After Lotze and Schott)

tectonics and normal crustal movements occurring at several geological periods. This is especially true of the fields in the Central Hannover district where there are salt structures of great complexity.

The term "salt structure" is here used to designate tectonic features produced in part or entirely by the flowage of salt. The term "salt stocks" is applied only to the salt core of such structures. The use of the term "salt dome" is restricted to salt structures in which the salt is fairly deep-seated and is overlain by domed strata.

In addition to the structures in which salt beds have upthrust their cover, there are folds in which the salt has lifted but not upthrust its cover. In some districts there are tectonic features that are unrelated to the flowage of salt. Further discussion of tectonics is confined to the headings of "Salt Structures" and "Non-Salt Structures."

SALT STRUCTURES

Age and thickness of salt deposits.—Most of the German oil fields are situated on salt structures in which Permian salt beds have either lifted or pierced their cover. The most widespread and thickest of these salt beds occupy the upper Zechstein formation at the top of the Permian. These deposits were precipitated by the evaporation of sea water in an inland basin that covered most of the region of northern Europe and a part of the British Isles (Fig. 3). The thickness of the Upper Zechstein in the central part of the basin, now occupied by the North German Plain, is not definitely known for it lies at depths of 10,000–12,000 feet

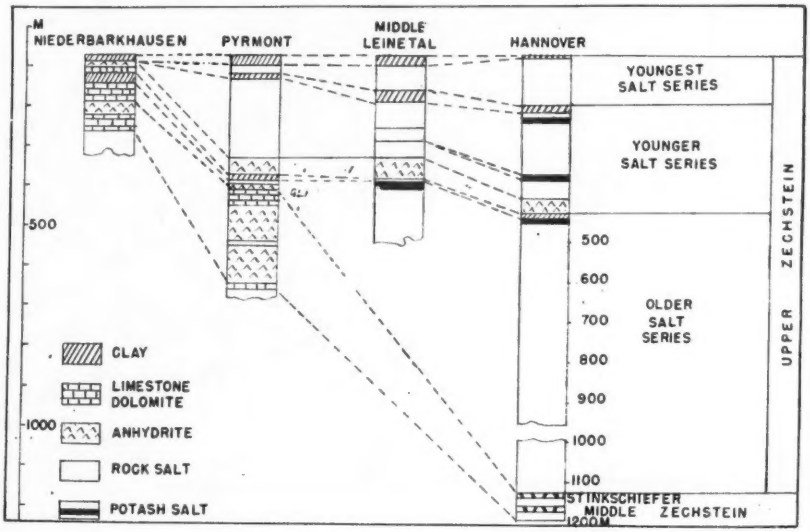


FIG. 4.—Sections showing thickness of Upper Zechstein formation. (After Lotze)

and has not been penetrated in wells, excepting in upthrust positions where it has been greatly thickened by flowage. It is estimated that it has a maximum thickness of approximately 5,000–6,000 feet. In the southeastern part of the plain, southeast of Hannover, the Upper Zechstein has a normal thickness of 2,000–2,500 feet, 90 per cent of which is rock salt (Fig. 4). Farther south toward the edge of the basin it shows a marked thinning and also a decrease in the percentage of salt. A thinning of the Upper Zechstein also occurs in the northern part of the North German Plain. At Stade, west of Hamburg, it is 750 feet thick and at Heide 500 feet thick. No information is available on the thickness of salt-bearing beds of Rotliegend age. They have been noted only northwest of Hamburg where a series

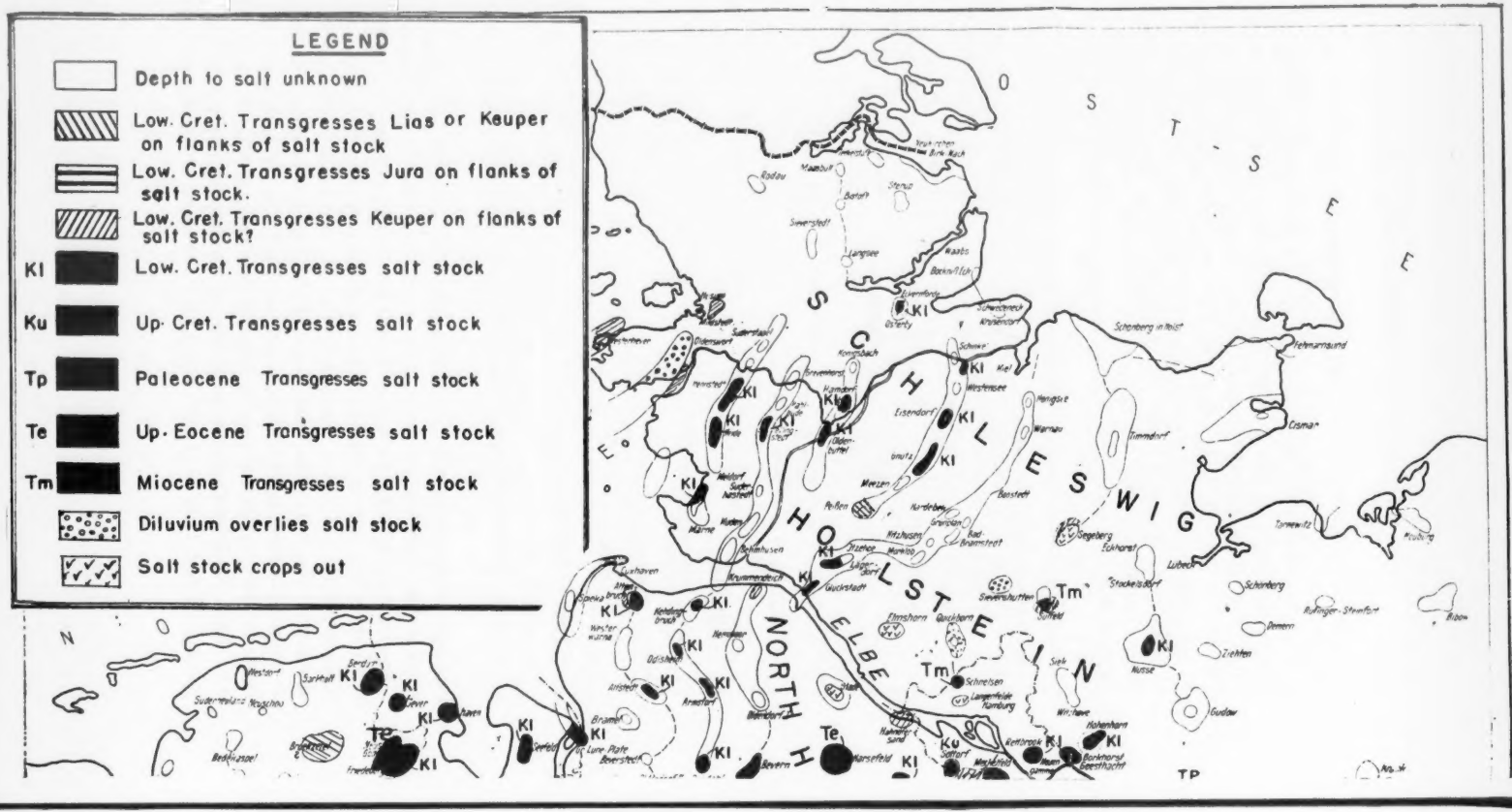

LEGEND
Depth to salt unknown
Low. Cret. Transgresses Lias or Keuper on flanks of salt stock
Low. Cret. Transgresses Jura on flanks of salt stock.
Low. Cret. Transgresses Keuper on flanks of salt stock?
Kl Low. Cret. Transgresses salt stock
Ku Up. Cret. Transgresses salt stock
Tp Paleocene Transgresses salt stock
Te Up. Eocene Transgresses salt stock
Tm Miocene Transgresses salt stock
Diluvium overlies salt stock
Salt stock crops out
O S T S E E
S C H L E S W I G
H O L S T E I N
N O R D
S E E
N
Kl
Te
Tm
Ku
TP

FIG. 5.—Map showing North German salt structures and formations directly overlying their salt core. (After Riedel)

of reddish clay marls, rock salt, and anhydrite, known as the Haselgebirge, forms the core of salt anticlines.

CLASSIFICATION

The German salt structures are herein divided into piercement, semi-piercement, and non-piercement types. No sharp line can be drawn between these types, but the information available on many of the structures does not justify the use of a more precise classification. The term "piercement type" is applied to those structures in which the salt has intruded all its cover except possibly a thin mantle of Upper Tertiary or Quaternary sediments. The term "semi-piercement" type is here used for all structures in which the salt has intruded only the lower part of its cover and domed the rest. Non-piercement types are those in which the salt has been thickened by flowage into the crest of a fold or dome but has not pierced any part of its cover. No distinction can be drawn between the last-named type and ordinary structures that involve clays and other plastic sediments, for some flowage into the crest of folds may be expected wherever such beds are folded under an appreciable load.

More than 200 salt structures are known in the North German Plain (Fig. 5). Many of these have been discovered since 1930 by geophysical prospecting and only slightly over half of them have been drilled; consequently, the depth and stratigraphic position of the top of the salt are unknown in many of them.

Pleistocene deposits occupy the surface of the low plain in which the salt structures are located and only about half a dozen show at the surface or have a topographic expression.

DESCRIPTION BY DISTRICTS

Central Hannover district.—This district includes the salt structures in the Hannover province that lie east of the Weser and south of the Aller rivers. It also includes the salt structures on the north bank of the Aller east of Verden. The latter lie south of the Pompeckj uplift and should be grouped with those south of the Aller.

Most of the salt structures in the Central Hannover district are of the piercement type in which the salt stocks are overlain by a thin mantle of Pleistocene clays and sands (Figs. 6–9). They commonly have a flat-topped solution surface and some show a residual cap rock 100–400 feet thick, composed chiefly of gypsum and known as the "Gipshut" (gypsum hat). Many of them are elongate in outline and are 1 to 10 miles long. The salt stocks are 2,500 to 6,000 feet wide and have steeply inclined or overhanging walls.

The structure bordering the salt stocks in the Central Hannover district is due to a combination of tangential folding and salt upthrusting. The part that these two forces have played in the formation of the salt structures is thought to be as follows.

During the early phase of the crustal movements that were initiated in Upper Jurassic time anticlines were formed in which the salt may not have up-

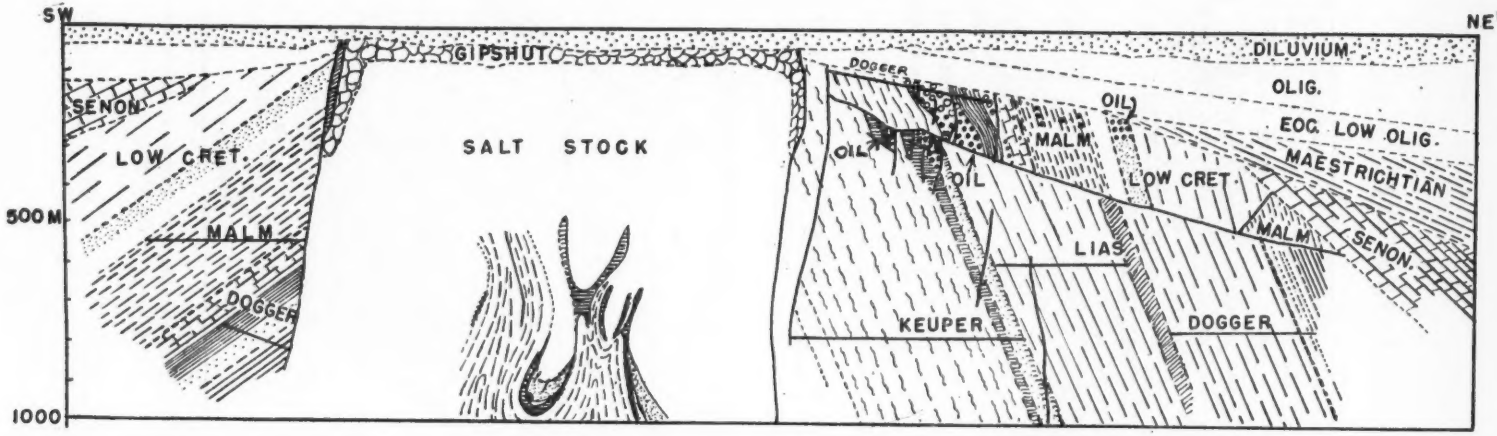


FIG. 6.—Cross section of Wietze salt structure with accumulation of oil on north flank. (After Kraiss)

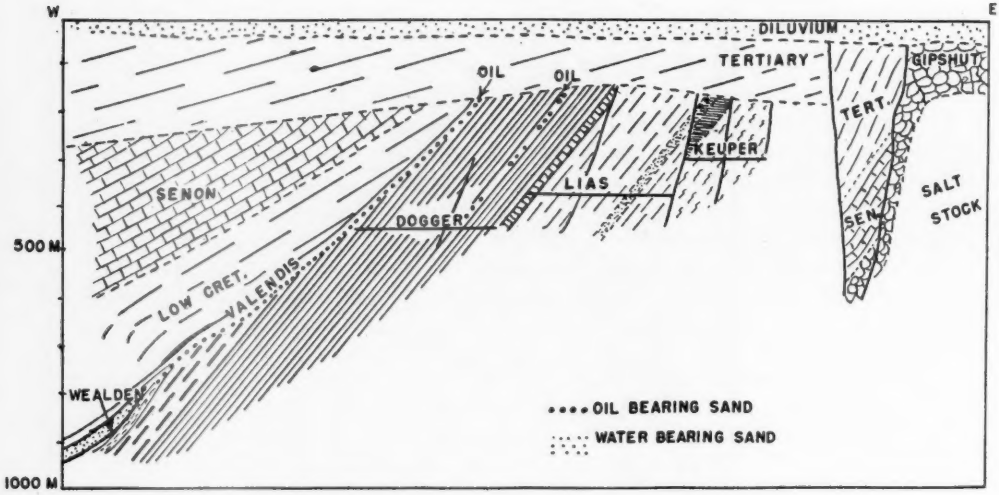


FIG. 7.—Cross section of west flank of Nienhagen-Hänigsen salt structure, showing oil accumulation. (After Kraiss)

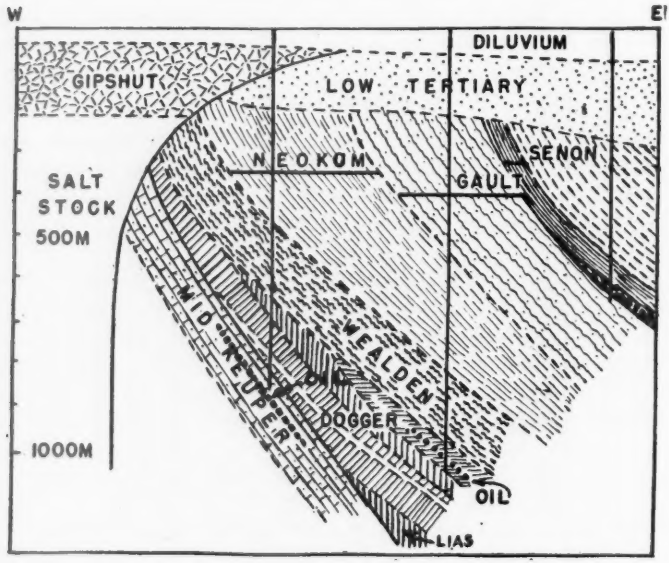


FIG. 8.—Schematic section of the northeast flank of Oedesse salt structure showing oil accumulation. (After Moos)

thrust its cover. Its failure to do so may have been due to the mild character of the folding and the absence of sufficient load to induce a plastic flow of the salt for at that time the sediments overlying the Zechstein were only 5,000 to 6,000 feet thick. These Upper Jurassic anticlines continued to grow during the Lower Cretaceous as is indicated by the thinning and overlapping of the Wealden on Upper Jurassic formations and the Valendis on the Wealden and older strata. During the Upper Cretaceous period the folds were covered by 2,500 to 3,000

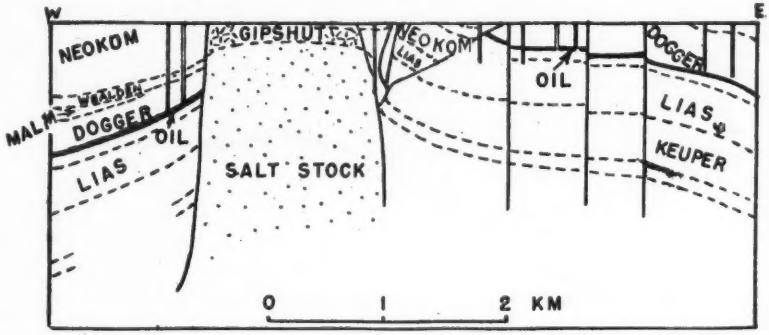


FIG. 9.—Cross section of Gr. Ilsede salt structure showing oil accumulation at Oberg. (After Schleh)

feet of calcareous sediments. In the latter part of this period some of the salt structures had a slight growth possibly as a result of gravitational loading. Because of the erosion that accompanied these periods of growth the Eocene generally overlies older formations on the flanks of the salt structures with a marked unconformity (Figs. 6–8). The added load produced by the accumulation of 1,500 to 2,500 feet of Tertiary sediments caused further upthrusting of the salt in late Tertiary time accompanied by faulting around the margins of the salt stocks, but no marked tilting of adjacent strata.

The non-piercement type of salt structures is found in the eastern part of the Central Hannover district. Among the largest of these are the Fallstein, Elm, and Hildesheimer Wald folds. Wells on the Fallstein dome penetrate the Middle Zechstein and show that it has been bowed upward about as much as the formations overlying the Upper Zechstein salt beds and therefore that the latter has not been appreciably thickened by flowage into the crest of the fold. In the broad, gently dipping Elm fold, which has a structural relief of approximately 3,000 feet, the Upper Zechstein salt beds have been bowed upward in a broad arch similar to the one in the overlying Triassic formations. Wells drilled on the crest of the dome show that the members of the Upper Zechstein occupy their normal sequence and have been thickened only slightly by flowage. In the more closely folded Hildes-

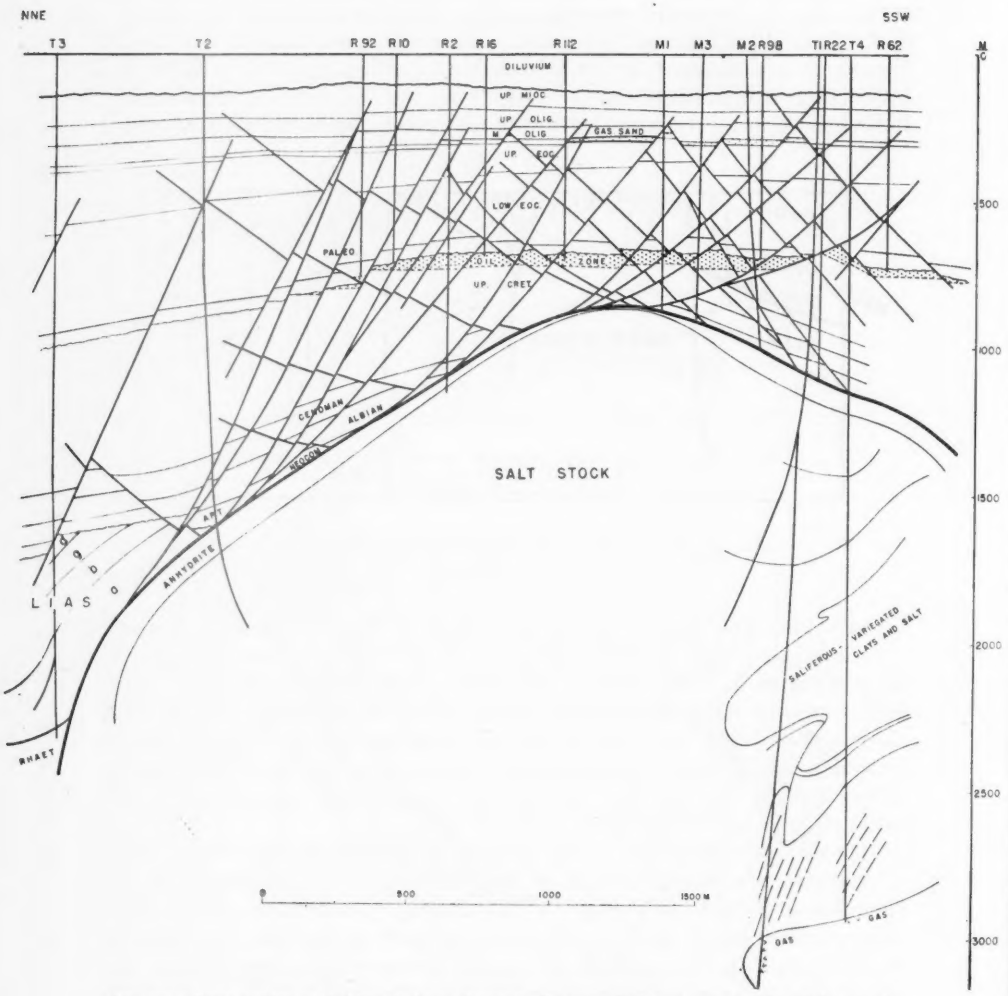


FIG. 10.—Cross section of Reitbrook dome showing oil accumulation on crest. (After Behrmann)

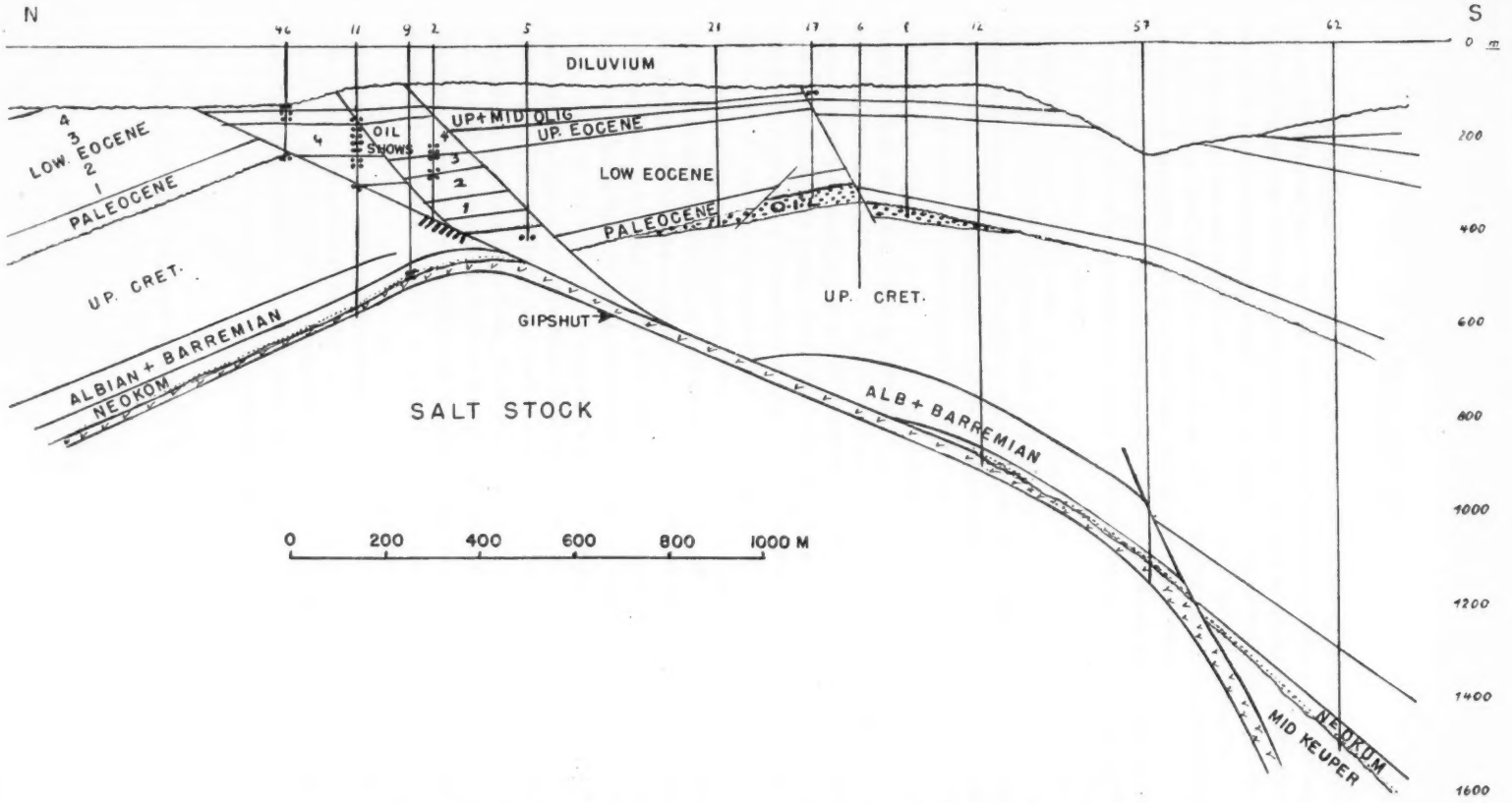


FIG. 11.—Cross section of Meckelfeld salt structure showing oil accumulation on crest. (After Behrmann)

heimer Wald anticline the salt beds, as revealed by mine workings, are folded disharmoniously with the overlying Triassic strata, but have not pierced their cover.

That the salt did not upthrust its cover in the above folds may be attributed to the fact that they began to form during Upper Jurassic time and received little sediments thereafter; hence, the Zechstein's overburden was insufficient to raise the plasticity of the salt to the point where it flowed freely into the crests of the folds. In the folds of the Thuringian basin, south of the Harz Mountains, the Zechstein salt also shows no piercement of its cover. This can be attributed to mild loading of the Upper Zechstein and to the slight thickness of the salt beds in the basin.

West Hannover district.—All German territory west of the Central Hannover district and south of the Pompeckj uplift is here described as the West Hannover district. Salt structures occur only along its northern margin, being absent elsewhere evidently due to the slight thickness of the Zechstein salt beds. The principal structures in the district are due to normal crustal movements and are described under a subsequent heading.

North Hannover district.—All salt structures between Schleswig-Holstein and the Central Hannover district are grouped in the North Hannover district. In general, this district embraces all territory between the Aller and Elbe rivers, excepting the narrow strip along the north side of the Aller which geologically belongs to the Central Hannover district. Hamburg Free State, in which the Reitbrook oil field is situated, is included in the North Hannover district.

Approximately 100 salt structures are known in the North Hannover district. Most of these have been discovered by geophysical prospecting during the past 15 years. In only about half of them has the salt been penetrated by exploratory wells. Most of these tests are located on the crest of the structures; consequently, they are not as well known as those south of the Aller. The following generalizations, however, can be made about their geology.

In the eastern half of the district most of the structures are of the piercement type in which the salt has upthrust most of its cover. In about half of the tested structures in this part of the district the salt stocks are transgressed by the Eocene or Paleocene; in the other half the salt stocks are directly overlain by the Pleistocene. In two of the latter, Luneburg and Stade, the salt stocks protrude in places above the cover of diluvium. Only four other salt stocks in the North German Plain show at the surface.

In the western half of the North Hannover district most of the salt structures are of the semi-piercement type (Figs. 10–11). The most westerly occupy anticlinal folds or horsts. In the exploratory wells drilled in the area, the salt stocks are commonly encountered beneath domed Tertiary and Cretaceous strata 2,000 to 3,500 feet thick consisting of the following.

Pleistocene sand and gravel
Tertiary clays and sands
Upper Cretaceous chalks, marls, and limestones
Lower Cretaceous (Albian-Hauterivian) marly and sandy clays and fine-grained sandstones

The Tertiary and Upper Cretaceous formations show an appreciable thinning across the salt stocks, and the Lower Cretaceous very little. The latter are 100–250 feet thick. The Hauterivian is most places directly overlies the salt stocks and transgresses strata ranging in age from the Lias to the Keuper on their flanks. The discordant angle is commonly 5°–10°.

Nowhere in the North Hannover district have Malm, Wealden, or Valendis strata been encountered on either the crest or flanks of salt domes.

At Stade, Odisheim, Altenbruch, and Neuhaus on the south bank of the Elbe, Rotliegend salt-bearing strata form the core of salt stocks and are transgressed by the Hauterivian. Similar structures are found north of the Elbe in Schleswig-Holstein.

Oldenburg district.—The area west of the Weser River and north of the west Hannover district, comprising a greater part of Oldenburg province, is here described as the Oldenburg district. About 40 salt structures have been discovered in this area, about half of which have been tested by exploratory wells. The salt stocks are encountered at depths of 2,000–3,000 feet, and are overlain by domed Tertiary and Cretaceous strata. In most domes Albian sandy beds transgress the salt stocks and Lias or older strata on their flanks. Non-marine Albian shales transgress Dogger and Lias strata on the northwest flank of the Etzel dome. This is the only locality where Dogger strata have been encountered in the area of the Pompeckj uplift. In the southeastern part of the Oldenburg district the Mucronaten Senon transgresses the Zwichenahn, Delmenhorst, and Emptinghausen salt domes. A deep test on the southeast flank of Zwichenahn encountered thick Valendis sands and Wealden bituminous shales beneath an unbroken sequence of higher Cretaceous formations. Nowhere else have Wealden and Valendis beds been encountered on the Pompeckj uplift.

Schleswig-Holstein.—The western half of Schleswig-Holstein is occupied by north-northeast-trending salt anticlines most of which have a core of Rotliegend salt-bearing clays. The oil-bearing Heide structure is the most extensively explored. It is 40 miles long and 2.5 miles wide. The Rotliegend core lies at depths of 2,500–3,500 feet and has steep to overhanging walls with the Zechstein formations tilted steeply or buckled into overturned subsidiary folds on its flanks (Fig. 13). Further down dip Lias and Keuper beds have been penetrated in a few wells.

A thin Neocomian brown sandy shale transgresses the crest and flanks of the salt stock. A sedimentary breccia occupies small pockets on the pre-Necomian eroded surface chiefly on the Upper Zechstein. This breccia is one of the principal oil reservoir rocks in the Heide fields. It consists of rock fragments derived from the Rotliegend, Zechstein, Keuper, and Lias.

Above the Neocomian are a thin series of Lower Cretaceous marly shales and 1,000–1,500 feet of Upper Cretaceous chalk, marl, and limestone. Above these is a thin mantle of Tertiary and Pleistocene sediments.

The Permian formations in the Heide area show the following characteristics.

The Upper Zechstein consists of the typical members of rock salt, anhydrite shale, *et cetera*, but is only 500 to 700 feet thick. The Middle and Lower Zechstein formations consist of alternating members of dolomite, anhydrite, chalk, and shale, with a thickness of 100 to 200 feet (Fig. 14).

The Lower Zechstein transgresses the Rotliegend formation, the upper members of which consist of 75 to 100 feet of variegated marly clays, with thin beds of calcareous sandstone, banded shales, and shaly limestones. These beds

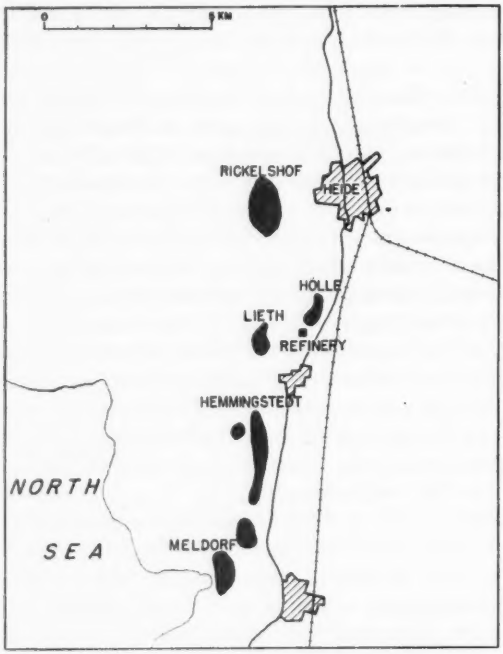


FIG. 12.—Heide oil fields. (After Deecke)

overlie a series of reddish brown clay containing rock salt crystals and thin beds of salt. This series, known as the Haselgebirge, is of great thickness. A well drilled on the Heide structure in 1938 to a depth of 12,762 feet (the deepest in Europe) ended in the Rotliegend. These Rotliegend salt-bearing clays have played a greater role in producing salt structures in the western half of Schleswig-Holstein than the Upper Zechstein, presumably because of the reduced thickness of the latter. In the eastern half of the province the salt domes have a core of Zechstein and lie at a fairly shallow depth and for the most part are directly overlain by Miocene or Pleistocene sediments. In four domes the salt stock shows

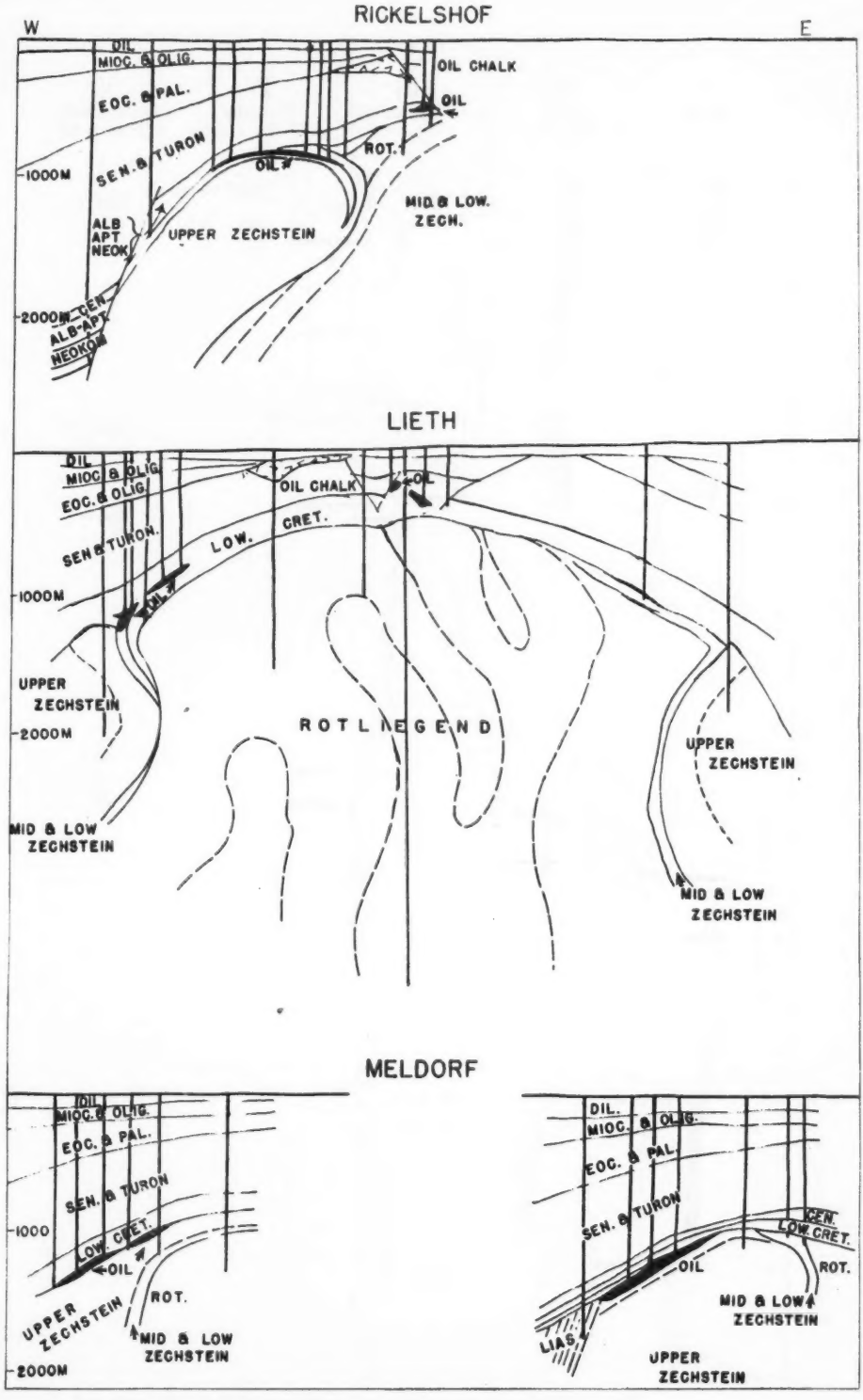


FIG. 13.—Cross section of Heide Rotliegend salt structure showing oil accumulation at Rickelshof, Lieth, and Meldorf. (After Weber and Kraiss)

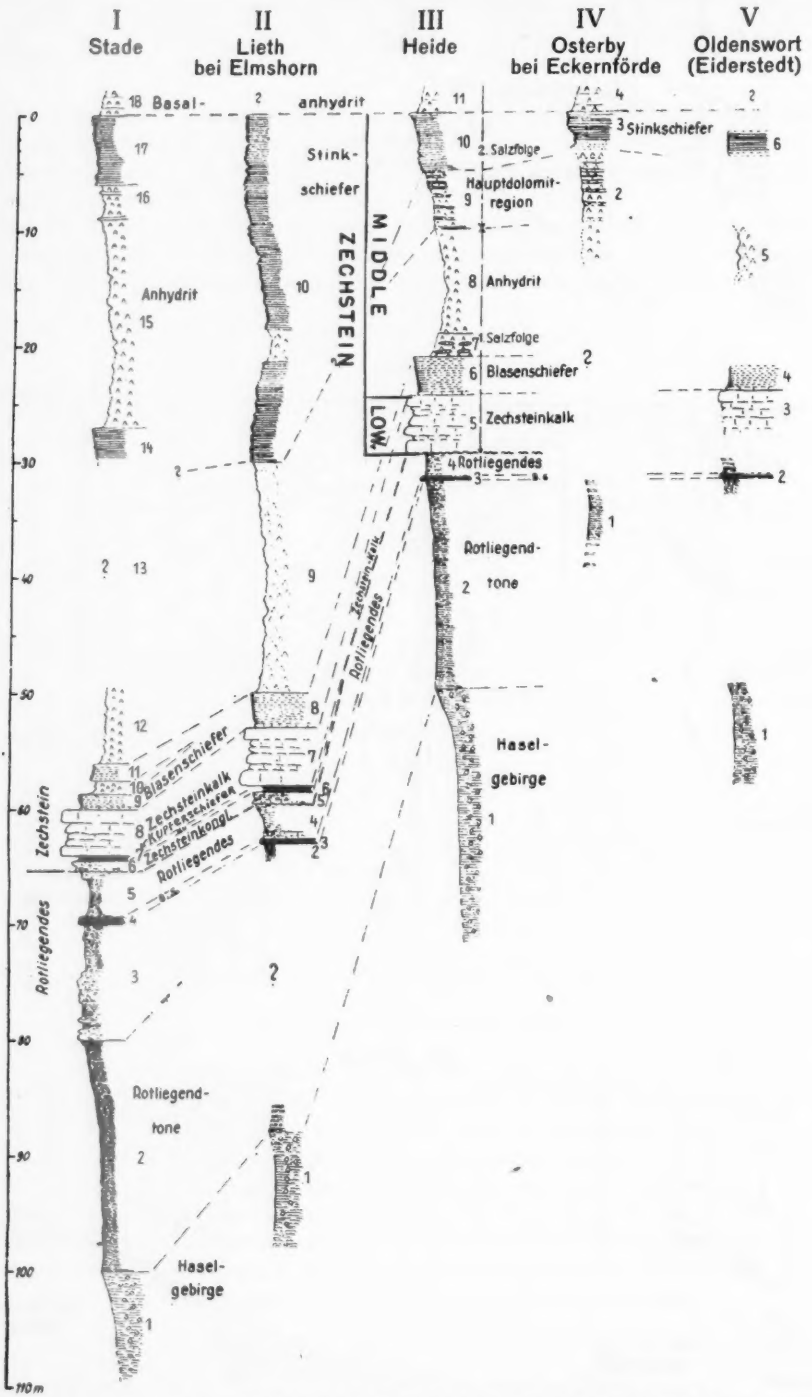
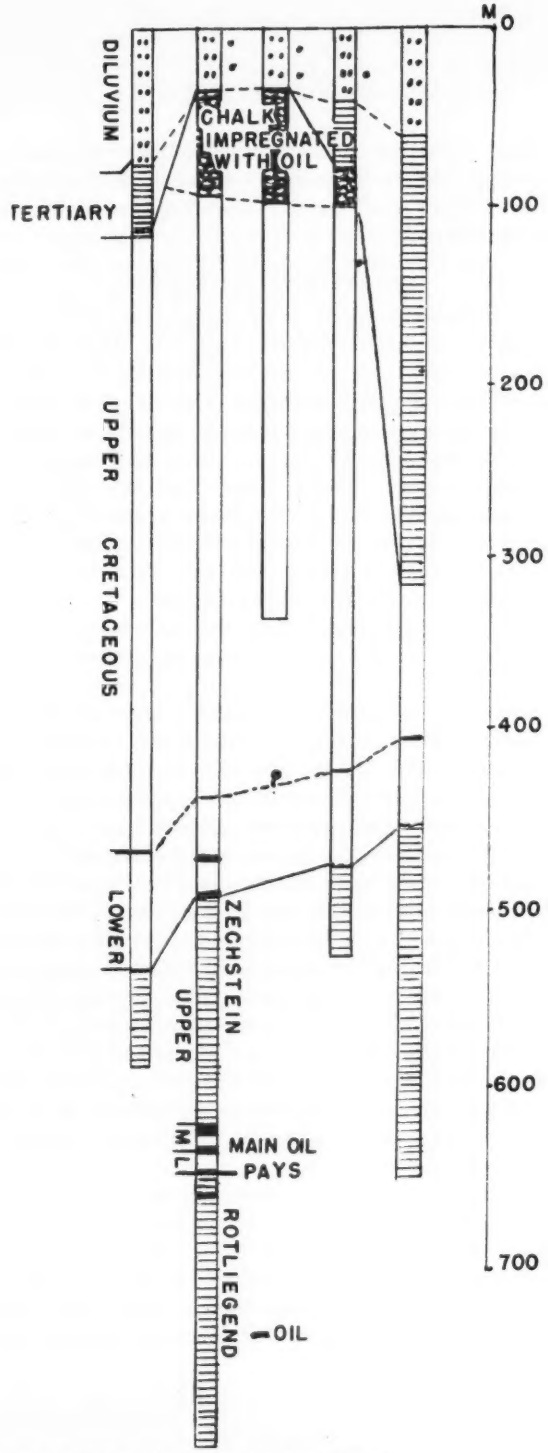


FIG. 14.—Sections showing Permian formations in Schleswig-Holstein and oil



sands in Heide fields. (After Schott and Kraiss)

at the surface. It is evident that the salt anticlines in the western part of Schleswig-Holstein were sharply folded and eroded before the deposition of the Neocomian. They had a slight further growth in the Upper Cretaceous and a more marked growth in the Upper Tertiary.

SUMMARY OF SALT STRUCTURES

The salt structures in the North German Plain have the following regional characteristics. Those in the Central Hannover and West Hannover districts are mostly of the piercement type, the salt being overlain as a rule by a thin cover of Pleistocene or Upper Tertiary sediments. They are very complex and show evidence of growth during the Upper Jurassic, Lower and Upper Cretaceous, Eocene, and late Tertiary time. Discordances occur at the base of the Portland, Serpulit, Wealden, Valendis, Albian, Upper Senonian (Mucronaten Senon), Eocene, and Pleistocene. The Jurassic and Lower Cretaceous periods of growth are contemporaneous with normal crustal movements. The Upper Cretaceous and Upper Tertiary periods of growth may have been due chiefly to the upthrusting of the salt resulting from gravitational load.

The crustal movements in the foregoing districts were confined chiefly to the salt structures. Intervening areas show a more or less unbroken stratigraphic sequence.

Most salt structures in the Oldenburg district are fairly deep seated domes and are overlain by 2,000–3,000 feet of Tertiary and Cretaceous strata with a mantle of Pleistocene. With the exception of the Pleistocene the formations show a slight doming over most salt stocks, due to the progressive upthrusting of the salt in Tertiary time. Some structures and possibly all had a slight growth during the Upper Cretaceous and a pronounced pre-Neocomian development.

In the western half of the North Hannover district the salt domes are similar to those in the Oldenburg district, excepting that many of them lie on salt anticlines and are transgressed by the Hauterivian instead of the Albian. In the eastern part of the North Hannover district and in Schleswig-Holstein a pronounced movement of the salt occurred in late Tertiary time. The late Tertiary growth of several stocks was sufficient to result in the removal of the Tertiary from the crest of some of the domes. In others the salt has pierced both its Cretaceous and Tertiary cover. Since the deposition of the Pleistocene there has been little or no movement in the salt. The few structures in which the salt stocks rise above the Pleistocene probably represent uneroded remnants of the "Gipshut" which were not covered by Pleistocene sediments.

The Cretaceous and Teritary movements probably were caused chiefly by the pressure exerted by the sediments overlying the salt. It is evident that the salt structures in the region north of the Central and West Hannover districts also had a considerable growth in pre-Lower Cretaceous time as is indicated by the fact that the Albian or Hauterivian directly overlie most salt stocks. This may have occurred during the late Jurassic crustal movements. It evidently was

accompanied by an uplift sufficient to cause the sea to withdraw from the region. The erosion that ensued produced a widespread peneplanation resulting in the removal of the Triassic and Jurassic formations over the salt stocks and the erosion of most of the Jurassic from intervening areas. That such an uplift and peneplanation took place is borne out by the fact that the Hauterivian or Albian transgresses Lias or Triassic formations on the flanks of salt structures. In only two of over 100 salt structures tested in the region north of the Central and West Hannover districts have beds between the Hauterivian and Lias been encountered.

The area from which these Jurassic and basal Lower Cretaceous beds are absent is known as the Pompeckj uplift. It was formerly thought that this uplift was limited to the eastern part of the North Hannover district. The information obtained in the deep wells drilled during the past 10 years in the region makes it evident that the uplift comprises probably all of the North German Plain north of the Hannover and West Hannover districts.

NON-SALT STRUCTURES

Anticlinal folds.—Anticlinal folding unaccompanied by the flowage of salt is more common in the German oil fields than is generally assumed. The fields discovered during the war along the Dutch border are low, gentle folds involving a thick series of Cretaceous and Jurassic strata with unconformities at the base of the Aptian and Wealden. Several other anticlinal folds have been mapped north and south of the Osnabrueck uplift (Fig. 5). Scarps on the flanks of this uplift form the Teutoburger Wald and the Wiehen and Weser Gebirge. The Bentheim fold lies along one of the main anticlinal axis. In the Central Hannover district there are several slight folds lying between salt structures that may be due entirely to normal folding. Minor folds of this character may be found throughout the North German Plain. Several anticlinal folds and domes unrelated to salt tectonics occupy the Thuringian basin.

Tilted fault blocks.—The oil fields in the Rhine Valley district occur within a fault graben through which the Rhine flows between Basel and Mainz (Fig. 15). This graben is about 20 miles wide and 180 miles long and includes a series of Tertiary and Mesozoic strata overlain by Pleistocene deposits. The formations along the margins of the graben are broken into a series of minor fault blocks in which the strata are inclined at low angles. Transverse faults cross the other faults at various angles. The fields on the German side of the Rhine occupy the eastern margin of the graben and are situated 6 to 15 miles northeast of Karlsruhe. The old Pechelbronn field in France lies along the western margin of the graben about 25 miles southwest of Karlsruhe.

Oil Accumulation

The role that the foregoing types of structure have played in the accumulation of oil in the German fields is here briefly reviewed.

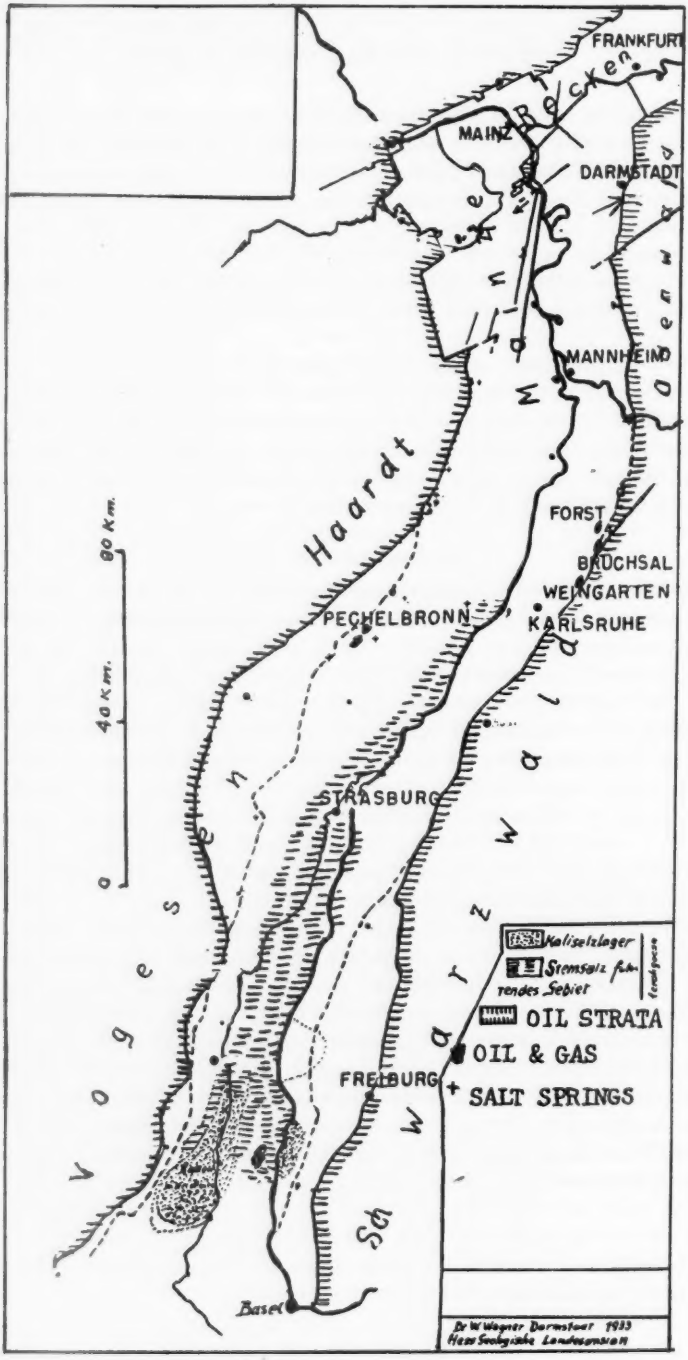


FIG. 15.—Sketch of Rhine Valley graben. (After Wagner)

Central Hannover district.—Practically all the fields in the Central Hannover district are situated on salt structures of the piercement type. It is doubtful, however, if the deformation produced by the upthrusting of the salt played an important role in the accumulation of oil. It seems likely that the chief factors in its accumulation are a combination of structural and stratigraphic traps that were formed during early stages in the growth of the folds. At any rate the tilting and faulting of the Mesozoic strata, together with the unconformable overlaps and porous sand lenses, which are responsible for most of the accumulation of oil in the district, are attributable to the early periods of tangential folding (Figs. 6–9). Although some accumulation may have occurred because of the upthrusting of the salt, it is probable that this upthrusting resulted in a greater wastage of previously trapped oil than in the accumulation of additional supplies.

The small size of the German fields, most of which do not exceed a few hundred acres in extent, may be attributed to the fact that only in localities where the oil was sealed in by faults, overlaps and updip lensing did it escape the dispersion that took place when the oil sands were tilted sharply and eroded in pre-Tertiary time. Most of the oil not trapped by the features mentioned then tended to migrate updip and reach the surface at the upturned edge of the strata or through the fracture zones bordering the salt. Evidence of this wastage is furnished by the "Teerkuhlen" in the faulted zone around the periphery of the salt masses.

The only accumulation of oil so far discovered in the non-piercement type of salt structures in the Hannover district occurs in a Middle Zechstein dolomite on the crest of the Fallstein anticline. The small production so far obtained may be attributed to the lack of reservoir rocks. The dolomite that yields the oil is reported to have a very low porosity. The failure to obtain oil in post-Zechstein formations in these folds can be attributed to the fact that the Jurassic and Lower Cretaceous oil-bearing formations are absent over the crests of the anticlines. These formations, however, offer prospects for accumulation in stratigraphic traps on the flanks of the anticlines.

West Hannover district.—Three oil fields and one gas field were discovered during the war in this district. They are located on gentle folds that appear to be unrelated to salt tectonics. The first to be discovered was the Bentheim gas field which was brought in during 1939 near Bentheim on the crest of a broad Cretaceous fold. The gas comes from a dolomitic limestone in the Hauptdolomit member of the Upper Zechstein. The first of the oil fields was discovered in 1942, 6 miles northwest of Lingen on a slightly tilted fault block. Production comes from two Valendis sands and several thin Wealden Lumachella shell beds. The Georgsdorf and Emlichheim fields discovered in 1943 are located on the plunging nose of low anticlines and obtain their oil from a Valendis sand. The latter field occupies a structure that extends across the Dutch border and on which the Coevorden field is situated.

Oldenburg district.—Only one small field has been discovered in this district.

It is known as the Etzel field and is located on the northwest flank of the huge deep-seated Friedburg-Gödens dome. The Zechstein salt stock is overlain by approximately 2,000 feet of slightly domed Tertiary and Upper Cretaceous strata with about 250 feet of Lower Cretaceous shales transgressing the salt stock and Dogger and Lias strata on its flanks. Some heavy asphaltic oil was found in a Eocene sand, also in Senonian chalks and in sandy beds at the base of the Lower Cretaceous on the crest and southeast flank of the dome. After considerable drilling, commercial production was obtained in 1942 from a Dogger epsilon limestone breccia on the northwest flank of the dome. The oil is a heavy paraffine oil, 0.98 gravity, and is high in sulphur.

North Hannover district.—Three fields (Sottorf, Meckelfeld and Reitbrook) were discovered in this district in 1937 and 1938. Sottorf is located on a shallow dome with arched Tertiary and a few meters of Upper Cretaceous strata overlying the salt stock which has a thick cap rock. On the flank of the dome the Albian transgresses Lias. The little oil produced from the field comes from the Upper Senonian Reitbrook beds. Oil showings are found in the Oligocene, Eocene, and Paleocene.

The Meckelfeld field lies on an east-west elongate salt dome with gently arched and faulted Tertiary and Cretaceous beds overlying the salt (Fig. 11). The salt stock is transgressed by Upper Neocomian strata which overlie the mid-Keuper on the flank of the dome. Most of the oil is obtained from the Reitbrook beds. Some oil and gas is also obtained from the basal sandy beds of the Neocomian.

The large Reitbrook field occupies the crest of a circular salt dome in which the salt stock is overlain by 2,850–3,500 feet of Tertiary and Cretaceous strata (Fig. 10). The salt stock is transgressed by Neocomian sandy shales which overlie highly tilted Lias beds on the flank of the dome. The formations on the crest of the dome are extensively broken by a grid of southwest-northeast and east-west faults dipping south or southeast. Most of the oil comes from the Reitbrook beds, the productivity of which is due to fissuring. Oil is found also in a few wells in a lower Eocene sand. Gas is obtained from a lower Oligocene sand and upper and lower Eocene sands. The producing area in the Reitbrook beds covers 1,000 acres and is fully developed. The reserves are approximately 1.4 million barrels.

Schleswig-Holstein.—Five fields have been discovered in the Heide Rotliegend structure, four on the west flank and one on the east flank. The first field discovered was Hölle which produced a little oil from the Cenomanian and Rotliegend during 1935 to 1940. The The main strike came in 1938 with the discovery of Middle Zechstein oil at Leith followed by more important discoveries in the same formation at Rickelshof in 1939. The next important development was the discovery of oil in the pre-Neocomian breccia at Rickelshof in 1940, at Meldorf in 1941, and Hemmingstedt in 1944. The principal production came from the Rickelshof field in 1940. The structure of the fields is very complex (Fig. 13). The reservoir rocks are limited in extent and controlled more by pre-Neocomian weathering than by structural position. The discovery of oil is, therefore, a hit-or-miss affair.

The operating company hopes to find reservoir rocks in the Lias or Keuper on the flanks of the structure that will provide larger and more persistent areas of accumulation.

Thuringian basin.—The only field discovered in this basin was developed when a flow of oil and gas was encountered in the bottom of the 3,000-foot level in the Volkenroda salt mine near Mentetroda in 1930. This discovery led to the drilling of more than 100 shallow wells yielding oil from the Hauptdolomit member of the Middle Zechstein. The wells varied from 160 to 260 feet in depth and many of them were drilled at angles of 45° in order to cross-cut the fractures from which most of the oil was obtained. Three producing areas were developed in a belt about 3 miles long, each of these occupying a gently folded anticline trending northwest and southeast. The fractures associated with the folding gave the compact Hauptdolomit its reservoir capacity.

Rhine Valley district.—Most of the oil in the Rhine Valley fields has been trapped adjacent to faults that offset gently dipping strata. The size of the producing fields is determined by the extent of the porous Oligocene sand lenses in which much of the oil is found. These sand lenses average a few feet in thickness and may be 500 feet wide and 1,000 feet long. Oil is also obtained from the Lower Dogger and the Schilfsandstein of the Middle Keuper.

Source of Oil

The oil in the Hannover fields probably is indigenous to the Lower Cretaceous and Jurassic formations in which most of it is found. It probably originated in the marine black shales, limestones, and marls that are present in these sediments.

The source of the oil in the Reitbrook, Meckelfeld, and Sottorf domes is debatable. It was assumed formerly that the oil found in the Upper Cretaceous chalks in these fields was derived from underlying Lower Cretaceous and Jurassic marine formations that were supposed to have been pierced by the salt. But as has been pointed out, it is doubtful whether such beds are present in the northern part of the North German Plain, except possibly in restricted synclinal areas where they escaped erosion during the period of Upper Jurassic peneplanation. The oil may come from Lias strata or Lower and Middle Zechstein formations.

The oil obtained in the Middle Zechstein dolomites at Volkenroda and Fallstein probably originated in the dark bituminous dolomitic shale members (Stinkschiefer and Kupferschiefer), of the Middle and Lower Zechstein. It also appears likely that the oil in the Heide fields has its source in these Permian strata.

Opinion as to the origin of the oil found in the Rhine Valley fields is divided between a Tertiary and Jurassic source.

Resume of Future Possibilities

PROSPECTS VIEWED IN LIGHT OF PAST DEVELOPMENTS

The important production obtained by deeper drilling of salt structures in the early Thirties aroused the belief that most of these structures, when properly

TABLE IV

German Crude Oil Production 1871–1945

(In Metric Tons)

| Year | Wietze | Edemissen-Ölheim | Tegernsee | Steinhagen | Oberg | Schwanewede | Hänigsen | Hänigsen | Hänigsen | Peine | Ahlten | Ahlten | Ahlten

tested, would yield oil and that the deep-seated domes north of the Aller might be as productive as the Gulf Coast salt domes in the United States. Several American and British oil companies entered the field and much exploratory work and deep drilling was done. These operations led to the discovery of 28 fields, but their total cumulative production to the end of 1945 has been less than 30,000,000 barrels. The poor showing of the German salt structures in comparison with the American Gulf Coast salt domes may be further emphasized by citing the following facts.

During 85 years of drilling operations only about 72 million barrels of oil have been produced from 26 fields on German salt structures and only 9 of these have yielded singly more than one million barrels. Actually only three fields, Nienhagen Wietze, and Reitbrook, are major fields and even their combined production is only about 50 million barrels. In contrast, the Gulf Coast salt domes to the end of 1944 had produced a total of approximately 2.5 billion barrels, or 500 times Germany's production from salt structures. In fact, three fields in the Gulf Coast each have produced twice as much as all the German fields together. This great contrast in the productivity of the salt structures in the two countries is apparent in the size of the productive areas and in the yield of individual wells. The average size of the German fields is between 200 and 300 acres, whereas the Gulf Coast salt-dome fields average 3,000 acres and the largest, the Conroe dome in Texas, has a proved area three times as great as all the oil fields in Germany combined. The yield per well of the Gulf Coast fields is also nearly ten times that of the German fields. Only a few wells in the latter have come in at more than a few hundred barrels and their settled production averages less than 50 barrels. The following reasons may be given for the failure of the German fields to yield as much oil as the American Gulf Coast fields.

Practically all the oil in the German fields comes from formations ranging in age from the Permian to the Cretaceous, whereas the producing formations in the Gulf dome fields consist of numerous Tertiary sands generally with a much greater thickness and permeability than the German producing fields. In addition, the cap rock in the Gulf Coast domes has yielded 200 million barrels, whereas to date very little oil has been obtained from the cap rock or "Gipshut" of the German salt stocks.

Another factor that has been in part responsible for the low production and small size of the fields in the Hannover district is the wastage of oil that took place when the Kimmeridgian folds in the Hannover fields were eroded in the Upper Cretaceous and breached by the upthrusting of the salt in Tertiary time. In the Gulf Coast fields the salt did not rise so near the surface as in the Hannover fields and the oil sands have a sufficient cover of impermeable clays to prevent much leakage of oil.

The failure to find oil in most of the deep-seated domes in the region north and northwest of the Central Hannover district is due to the lack of porous zones in the Upper Cretaceous strata that overlie the salt in most of the domes and the

absence of the oil-bearing Lower Cretaceous and Jurassic formations of the Hannover district. It was formerly assumed that these formations were well developed in the region and that they might be found to be more productive than in the Central Hannover district. The fact that they had not been encountered on the crest of the earlier-tested domes and were absent in upthrust strata bordering the few piercement salt structures present in the region was attributed to an unconformity which was assumed to be restricted to the upthrust area and to have resulted from the late Jurassic and early Cretaceous growth of the domes. The idea was generally held that these formations would not be eroded from the crest of deep-seated domes and would be encountered on the flanks of others in overlapped positions and in either case they would furnish ideal oil traps. But in 2 decades of exploratory drilling during which many of these domes have been tested by wells drilled both on their crest and flanks, the important Lower Cretaceous and Jurassic oil-bearing formations have not been encountered, and it is therefore becoming increasingly doubtful whether such formations are present in this part of the North German Plain, except possibly in synclinal basins. If this is proved to be correct then the chief prospect of obtaining production from these domes will be in the Upper Cretaceous and Tertiary formations that occupy the crest of most of the domes.

The Upper Cretaceous generally appears to be too impervious to yield oil, except in the belt between Hamburg and Bremen where the Upper Senonian Reitbrook beds are developed. These porous chalky limestones, however, are in many places absent over the crest of domes in this belt because of pre-Eocene uplift and erosion. In other domes their oil content has been wasted by leakage because of an insufficient Tertiary cover.

The sandstones in the Tertiary should furnish good reservoir rocks, but to date little oil has been found in them. They may be unproductive because of the scarcity of sourse material in the Tertiary and the difficulties offered by the Tertiary clays to the migration of oil from deeper formations.

Although there are geological reasons for not being especially optimistic about the discovery of additional reserves of oil in the North German Plain, no doubt some new fields will be found. From the available information the best prospects for such discoveries appear to be as follows.

LOCALITIES OFFERING BEST PROSPECTS

The discovery during the war of three fields on gentle folds near the Dutch border is likely to result in other similar discoveries in the locality. Fair chances also exist for the discovery of new fields in the belt of folds bordering the Osnabrueck uplift where the Lower Cretaceous and Jurassic oil-bearing formations of the Central Hannover district are well developed.

The discovery of moderately large wells in the Permian at Heide previous to the war was formerly regarded as the beginning of an important new oil-field development in northwest Germany. But despite the development of 5 separate

fields, production has declined from its peak of 1,619,429 barrels in 1940 to 880,719 barrels in 1944. This decline is due to the influx of water and the exhaustion of the limited reservoirs. Because of the complexity of the structure and the patchy nature of the reservoir rocks it is difficult to appraise future prospects but it is thought that the best chances for further production is on the south end of the structure. Whether other fields similar to those at Heide will be found in Schleswig-Holstein and in the area bordering it south of the Elbe is debatable. Exploratory drilling in the region so far has been unsuccessful either in discovering commercial production or in finding oil impregnated chalks which are regarded as good indications of oil at greater depths.

A slight possibility exists that fields similar to Reitbrook may be developed on some of the untested domes in the North Hannover and Oldenburg districts from the crest of which the Reitbrook beds have not been eroded and where they have a thick Tertiary cover, and are fractured by faulting. Some prospects are present in this region of finding production in Lias and Rhaetic sands on the flanks of salt structures and here as elsewhere in the North German Plain low folds may be present between the salt structures that should have good oil possibilities.

Small fields similar to those discovered during the war may be developed in the Central Hannover district. The salt structures and intervening folds lying along the Aller probably offer the best prospect for the discovery of such fields. Possibilities of sedimentary traps also exist in this belt where formations may overlap the Pompeckj uplift.

Minor fields may be found along the margins of the Rhine Valley graben both in France and Germany, but the discovery of additional fields, however, will no doubt come slowly, and the yield of any new fields, like the discovered ones, will probably be small.

The only part of Germany lying outside of present producing districts that has oil possibilities is the Munich Tertiary basin, lying north of the Alps. The German part of this basin is 200 miles long and 50 to 60 miles wide. It is regarded as prospective oil territory because of the following facts. A thick series of Tertiary and Cretaceous marine formations occupy the southern part of the basin. Small volumes of gas and some heavy oil have been encountered in Miocene and Oligocene sands at Wels and Leoprechting in the eastern or Austrian part of the basin. Seepages of oil issue from Tertiary sands exposed in the Flysch zone on the south border of the basin and some oil has been produced at Tegnersee near one of the seepages. Important oil fields with a 1944 production 70 per cent greater than the German fields were discovered during the war in the Tertiary basin northeast of Vienna.

Conclusions

In conclusion it may be pointed out that although there are possibilities of discovering additional fields in several districts in Germany, the prospect of finding important new production does not justify much exploratory drilling during

the reconstruction period. Some exploitation drilling may be warranted in recently discovered fields in which flowing wells yield a good initial production. If any exploratory work is undertaken in will probably be carried out under the direction of the Military Governments. In the American zone in which little oil is produced the only districts that have oil possibilities worthy of attention are the Rhine Valley graben and the Munich Tertiary basin. In both of these districts the potential oil-bearing formations are widely concealed by unconformable sediments of Upper Tertiary and Quaternary age so that surface mapping can contribute little information on the oil possibilities of the districts.

Since oil in the Rhine Valley graben is confined to narrow porous sandstone lenses, the search for new fields there must depend chiefly on exploratory drilling, which, in view of the small production that may be looked for, can scarcely be justified at the present time.

In the Munich Tertiary basin, however, geophysical prospecting should yield information as to the thickness of the Tertiary and Cretaceous sediments and the presence of structures favorable to the accumulation of oil. But before such work is planned, all the information obtained in former geophysical surveys of the basin together with deep well data should be assembled. Extensive geophysical prospecting and some exploration drilling was done in the basin during World War II.

Without active geophysical prospecting and exploration drilling leading to the discovery of new fields, the production of crude oil in Germany will decline rapidly. In the past production has been maintained only by the discovery of new fields. Present proved reserves are estimated at 25 to 30 million barrels.

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VOL. 30, NO. 9 (SEPTEMBER, 1946), PP. 1585-1588, 1 FIG.

GEOLOGICAL NOTES

QUIMBYS MILL, NEW MEMBER OF PLATTEVILLE FORMATION, UPPER MISSISSIPPI VALLEY[1]

ALLEN F. AGNEW AND ALLEN V. HEYL, JR.[2]
Iowa City, Iowa, and Platteville, Wisconsin

In the course of investigations made by the United States Geological Survey in the Wisconsin-Illinois-Iowa mining district during 1943–1945, several of the stratigraphic problems of the Middle Ordovician beds were critically examined, and refinements of the section were accomplished. One of the more important stratigraphic problems dealt with the "glass rock" beds of the mining district.

Although the name "glass rock" had been applied most often by both miners and geologists to the limestone unit underlying the Spechts Ferry ("clay bed") shale member of the Decorah formation and overlying the McGregor ("Trenton") limestone member of the Platteville formation, the name had also been applied to a phase of the middle or Guttenberg ("oil rock") member of the Decorah formation, as well as to the lower beds of the McGregor. More recently, geologists have also referred to the limestone unit lying between the Spechts Ferry and McGregor, mentioned first in this paragraph, as a lithologic facies of the Spechts Ferry.

It was found in the course of the investigation that the main "glass rock" beds constitute a definite stratigraphic unit which underlies the Spechts Ferry shale member of the Decorah formation and overlies the McGregor limestone member of the Platteville formation. This unit of the Platteville formation for which the writers propose the name Quimbys Mill member consists of limestone and dolomite in medium to thin beds which are separated by thin carbonaceous shale laminae (similar to the "oil rock" of the Guttenberg limestone member of the Decorah formation). The limestone is finely granular, pinkish to purplish brown, and very dense, so that it breaks with a conchoidal fracture, ringing and splintering like glass. This characteristic in all likelihood gave rise to the name, "glass rock," which was first applied in one of the early reports on the geology of the mining district.[3] The dolomite is lighter in color, more granular, and only slightly less dense than the limestone. The limestone is fossiliferous, with an abundance of brachiopods and trilobites.

[1] Manuscript received, July 6, 1946. Published by permission of the director of the Geological Survey, United States Department of the Interior.

[2] United States Geological Survey.

[3] James Hall and J. F. Whitney, "Physical Geography and Surface Geology [of the Lead Region]," *Geol. Survey of Wisconsin*, Vol. I (1862), p. 163.

The writers propose the name Quimbys Mill member for this unit because of the excellent exposure of these beds in the old quarry at Quimby's Mill near the Fever River, in the hamlet of Etna, Wisconsin (SE. $\frac{1}{4}$, SE. $\frac{1}{4}$ Sec. 11, T. 1 N., R. 1 E.), which is now almost deserted. At the type locality the Quimbys Mill unit is 12 feet thick, the upper 6 feet being composed of dolomite with carbonaceous shale partings, whereas the lower 6 feet are limestone, with similar shale laminae.

The Quimbys Mill unit thins toward the northwest and thickens southeast, becoming completely a dolomite in the latter direction.

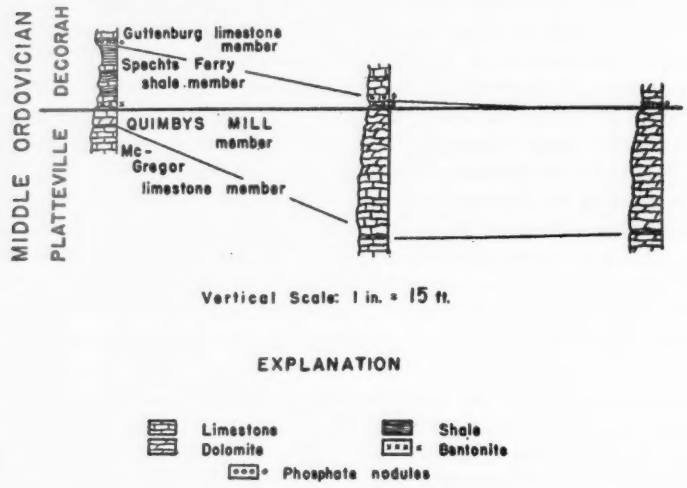

FIG. 1.—Diagram showing regional relationships of Quimbys Mill member of Platteville formation to adjacent stratigraphic units.
Localities:
1. City Quarry, Lancaster, Wisconsin, NW. $\frac{1}{4}$, NW. $\frac{1}{4}$, Sec. 3, T. 4 N., R. 3 W.
2. Type section, quarry at Quimby's Mill, Etna, Wisconsin, SE. cor., Sec. 11, T. 1 N., R. 1 E.
3. Quarry east of Calamine, Wisconsin, near SW. cor., Sec. 16, T. 3 N., R. 3 E.

The contact of the Quimbys Mill member of the Platteville formation with the McGregor limestone member below is well marked in the mining district and at the west, as there is a difference in color between the limestones, the McGregor being grayish; also there is ordinarily 1 to 3 inches of dark brown, carbonaceous shale at the base of the Quimbys Mill. This basal shale is not present at the southeast but the units can still be recognized. The contact is conformable.

The upper surface of the Quimbys Mill, however, is probably one of disconformity, as it is solution-pitted. The upper few inches of limestone or dolomite of the Quimbys Mill shows involutions containing Spechts Ferry sediments; where

the Spechts Ferry is absent (for it thins toward the east, pinching out in the vicinity of Darlington, Wisconsin, T. 2 N., R. 3. E.), the involutions contain basal Guttenberg sediments.

The fauna of the Quimbys Mill has not been studied in detail, but it suggests the equivalency of these beds with the middle part of the Black River of the New York-Ontario section.

Three graphic sections, showing the regional relationships of the Quimbys Mill and adjacent beds, are herewith presented (Fig. 1).

OÖLITE AND OÖLITH[1]

RONALD K. DEFORD[2] AND W. A. WALDSCHMIDT[2]
Midland, Texas

In most dictionaries and glossaries *oölite* and *pisolite* are defined as rocks, and no name is provided for the individual spheroidal grains. If the usage of a British textbook[3] were generally adopted, the confusion would be avoided. The following definitions are therefore recommended.

An *oölite* is a rock made up of an aggregate of small spheroidal bodies, called *oöliths*, held together by interstitial cementing material. The normal diameter of an oölith is less than one millimeter. The name *oölite* comes from the resemblance to fish roe.

A *pisolite* is a rock made up of an aggregate of spheroidal bodies, called *pisoliths*, held together by interstitial cementing material. The normal range of diameters of pisoliths is 2 to 10 millimeters. The prefix *piso* is derived from a Greek word for *pea*.

For exact definition it is recommended that the geometric intervals of the following grade scale be used.

Name of Grain	*Diameter of Grain (Millimeters)*
Pisolith	1.0–10.0
Oölith	0.1– 1.0

Similar spheroidal bodies with diameters outside the 0.1–10.0 mm. range are so rare as to justify special mention if found.

The double o in oölite is not pronounced as one syllable as in *zoo* but as two syllables as in *zoölogical*. The first *o* is accented and pronounced like the *o* in *old;* the second *o*, like the *o* in *obey*.[4]

[1] Manuscript received, July 18, 1946.

[2] Argo Oil Corporation.

[3] F. H. Hatch, R. H. Rastall, and Maurice Black, *The Petrology of the Sedimentary Rocks*, 3d ed. (London, 1938), pp. 175–78.

[4] *Webster's New International Dictionary of the English Language*, 2d edition, unabridged, G. & C. Merriam Co. (1934).

A recent, partly alternative proposal[5] should be mentioned: "*Oöid*—the individual tiny spheroid in an oölitic rock. Here used in preference to the term *oölith* of some authors to avoid confusion with *oölite* and *oölitic*."

[5] P. E. Cloud, Jr., V. E. Barnes, and Josiah Bridge, "Stratigraphy of the Ellenburger Group in Central Texas—A Progress Report," *Univ. Texas Pub. 4301* (June, 1945), p. 136.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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DISCUSSION

TECTONIC FRAMEWORK OF NORTHERN SOUTH AMERICA, BY FRITZ E. VON ESTORFF[1]

VICTOR OPPENHEIM[2]
Bogotá, Colombia

The interesting paper by Fritz E. von Estorff,[3] "Tectonic Framework of Northwestern South America," is a timely contribution to a tectonic interpretation of northwestern South America.

Although correct in its broad lines, many objections could be raised, regarding the continuous interpretation of the structural trends and their generalized application to other parts of the Continent, as attempted by von Estorff.

The presence of northeast- and northwest-trending structural lines in Colombia, Venezuela, Panama, Ecuador, and northern Perú is evident from the study and distribution of the main mountain ranges and their typical bifurcating branches; however, a hypothesis of continuous trends, applied to the whole of northwestern South America and based only on incomplete evidence, may appear too simplified for tectonically as complex a part of this continent.

In outline the structural pattern suggested by von Estorff would correspond with a type that could be produced, if great compression forces acted on this part of the continent along a north-south line. Evidently the tectonic forces that acted upon and shaped this part of South America are manifold and complex. This accounts for the distinctly east-west structural trends observed in the great massif of the Sierra Nevada de Santa Marta,[4] that von Estorff does not mention; also the similar trends observed by the writer in the Tertiary sediments of the Pacific Coast of Colombia, to cite only a few instances where the structural trends are not quite in accordance with von Estorff's pattern.

Upon closer study, it also seems that the division of areas into "positive" and "negative" is rather loosely applied as based on topographic forms related to an arbitrary 6500-foot-level, instead of being based on distinct geological and structural elements, bearing on the hypothesis.

The coincidence of the topographically high areas, with areas of presumably pre-Paleozoic rocks, to which von Estorff refers, as "positive," requires additional interpretation, since these areas are mostly topped by young Tertiary andesites and grano-diorites, or even recent lavas in Ecuador and the Nevado de Ruiz group of peaks of the Cordillera Central in Colombia. Furthermore, the age of the underlying rocks of the high areas is generally very uncertain, since magmatic rocks of different ages appear intermingled and are practically inseparable. Thus they can not be assumed as pre-Paleozoic.

Von Estorff's idea, bearing on the occurrence of oil-producing structures in areas of intersection of "negative" trends, appears very original, but would probably require additional evidence that might be supplied by future discoveries.

Finally, the application of von Estorff's theory to other parts of South America seems

[1] Manuscript received, June 11, 1946.

[2] Consulting geologist.

[3] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 4 (April, 1946), pp. 581–90; 4 figs.

[4] Victor Oppenheim, "Geología del Departamento de Magdalena," *Compliación de los Estudios Geológicos Oficiales*, Vol. 5 (1942). Bogotá, Colombia.

to the writer questionable. Although the trend of the Atlantic Coast of Brazil is northeast, the most important uplifts and foldings along this coast show distinctly different trends. Thus, the post-Triassic uplifts of southern Brazil and Uruguay trend east-southeast; also the Gondwanid folding of the Sierra Ventana on the coast of Argentina trends toward the east; the Brazilides on the other hand trend due north; the prevailing trend of the shield rock along the coast of Pernambuco in northern Brazil is also due east. The Pacific Coast of Chile with its Andean ranges between 18° and 50° Lat. S., shows a persistent north-south structural trend.

The foregoing evidences suggest that, although northeastern and northwestern structural trends undoubtedly are present in the framework of South America, particularly in its northwestern part, the structural mosaic of the continent is, nevertheless, made up of a complex pattern of blocks, which direction depends not only on isostatic forces, but also on horizontal tensional stresses, that are variable in different parts of the Continent, and which in turn account for the different structural trends in the ancient as well as more recent rock masses in different parts of South America.

The present shape of South America suggests the effects of tensional and compressional forces; the structural trends are thus dependent on the direction of these forces and need not follow the rigid pattern, as outlined by von Estorff.

Thus, correct for Colombia, southwestern Venezuela, Panama, southern Ecuador, and eastern Perú, as outlined by the present mountain ranges, the northeastern and northwestern structural trends are not the only ones in these territories; they also may form part of complex tectonic patterns in other parts of South America, but their occurrence is conditioned by the prevailing stresses.

Von Estorff's paper is well illustrated and his attempt to a structural hypothesis very useful. It will be of help in the future work on the problems of South American tectonics.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

THE GEOLOGICAL RESULTS OF THE SEARCH FOR OILFIELDS IN GREAT BRITAIN, BY G. M. LEES AND A. H. TAITT

REVIEW BY D. A. GREIG[1]
New York City, N. Y.

"The Geological Results of the Search for Oilfields in Great Britain," by G. M. Lees and A. H. Taitt. *Quar. Jour. Geol. Soc. London*, Vol. 101, Pts. 3–4 (1945), pp. 255–317; 5 pls.

The reading of this paper before the Geological Society of London on December 6, 1944, must have provided a long-awaited sequel to an earlier address in 1937 before the Society by G. M. Lees and P. T. Cox. In that paper, the authors outlined the geological basis for the present search for oil in Great Britain (the first serious exploration was conducted but never completed by the British Government in 1918–1921 and, despite the drilling of eleven wells, resulted in the discovery of only one small producing well at Hardstoft in Derbyshire).

This recent publication supplements the former and is a factual summary of the results obtained so far by the D'Arcy Exploration Company's[2] investigation of the prospects in five interesting geological settings of Great Britain in (1) the oil shale districts of Scotland, (2) the Permian basin of northeastern Yorkshire, (3) the Triassic basin area of Lancashire, (4) the eastern Midlands, and (5) in southeastern England (the Weald). In addition, reference is made to work done in Staffordshire and Shropshire. Almost half the paper, however, is devoted to a detailed description of the Eakring district, and the neighboring regions in the eastern Midlands of England, where the D'Arcy company was successful in discovering a group of four fields which, under war-time pressure, produced up to September, 1944, about 310,233 tons (2,254,500 barrels) of good-grade crude from the Millstone Grit and Lower Coal Measures.

To those who have been following the search for oil in Britain, and especially to those who are familiar with the details of British stratigraphy, this paper can not fail to be of the greatest value. It is difficult to enumerate the "high-lights" in a publication so packed with data, but especially interesting are the authors' remarks regarding such enigmas as the lack of commercial pools in the once-promising Weald of southern England, the puzzling origin of the oil feeding the ultra-shallow accumulation of Formby in Lancashire, and the age of the source-beds in the Eakring district, *et cetera*.

Two aspects of their work in Britain mentioned by the authors, apart from the primary and successfully accomplished objective of finding oil, appear to warrant emphasis. The first is the company's development of arc-refraction shooting (fan-shooting) to a point where the method can be used for outlining relatively minor structural features. (Reflection shooting has given generally unusable results in the eastern Midlands.) And the second is the great gain in subsurface geological knowledge accruing to the country as a result of D'Arcy's and the other competing companies' drilling campaigns. Valuable new coal reserves in the eastern Midlands and potash minerals in the Permian basin have been discovered incidentally by D'Arcy.

[1] Standard Oil Company (N. J.) Review received, June 27, 1946.

[2] Exploration subsidiary of the Anglo-Iranian Oil Company.

The paper is well illustrated by maps, well logs, cross sections and tables. It is concluded by an outline of the company's proposals for future work and by the remarks of a number of leading British geologists during the discussion which followed the presentation of the address.

THE SCHOLAR AND THE FUTURE OF THE RESEARCH LIBRARY, BY FREMONT RIDER

REVIEW BY MARCUS A. HANNA
Houston, Texas

The Scholar and the Future of the Research Library, A Problem and Its Solution, by Fremont Rider, librarian, The Wesleyan University Library. 236 pp., 1 chart, 2 photographs of cards. Hadham Press, New York City, New York (1944).

In this book the author gives statistics regarding the growth of libraries. Although the rate of growth for the next 100 years may differ somewhat from the estimate, it is evident that additional library space will continue to be a serious problem.

The contents of the book are chaptered as follows.

THE PROBLEM

1. The Growth of American Research Libraries
2. What Do We Mean by "Research Library"?
3. The Four Main Factors of the Growth Problem
4. Past Attempts at Solution—"Weeding out"
5. Past Attempts at Solution—Economies in Method
6. Past Attempts at Solution—Inter-Library Cooperation

THE SOLUTION

1. Micro-Cards
2. Micro-Cards—Their Micro-Text
3. Micro-Cards—Their Catalogue Card Format
4. Micro-Cards—Their Entry Headings
5. Micro-Cards and Cataloging Analysis
6. When the Main Research Library Consists of Micro-Cards
7. The Publication and Sale of Micro-Cards
8. Library Control over Micro-Card Publishing
9. Copyright and Micro-Card Publication
10. The Use of Micro-Cards for Certain Special Classes of Material
11. Micro-Cards—When?

The author points out the inception of the use of micro-text by the unknown pioneer who took a picture of a page with a 35-mm.-film camera. Since then the 35-mm. photographic reproduction has been more or less standard. Changes have been so rapid that now it is possible to get 250 pages of micro-text on the back of a single $7\frac{1}{2}$-$\times 12\frac{1}{2}$-cm. catalogue card, and it seems possible with moderate improvements to put 500 pages of micro-text on the back of such a card. Any improvements in such micro-text reproduction will not jeopardize the use of previously existing cards, but rather improve their resolution and readability. The author's plea is *to begin to issue something at once.*

The geologist is not as much concerned with the future growth and space requirements of the larger libraries as he is with having publications immediately available. Under the Rider Card Catalogue System adequate facilities could be maintained by local groups or individuals. For instance, cards could be carried in one's pocket which would contain all the publications of the American Association of Petroleum Geologists. Although cost of issuance of such is uncertain, estimates suggest that such costs would be very reasonable.

It would seem that the time is ripe to put our support behind a movement to secure cards of geological literature for our membership. Many problems are involved, but are

not insurmountable. For instance, what will happen to the stock of back numbers now held by many organizations, or should manuscripts be run directly to cards and not ever printed in book form, etc. The question is not "when will micro-text come" but how can we better advance and utilize what is here. Many excellent papers probably would have appeared if the possible writers had available the literature for reference work. Who knows the increase in reserves which might result from greater availability and study of micro-text geological and allied literature?

RECENT PUBLICATIONS

ARGENTINA

*"Contribución al Conocimiento Geológico de la Precordillera Sanjuanino-Mendocina" (Geology of the Precordillera of San Juan and Mendoza), by Osvaldo Bracaccini. *Y. P. F. Bol. Inform. Petroleras*, Vol. 23, No. 260 (Buenos Aires, April, 1946), pp. 259–74, Figs. 8–20. 2d part of article; 1st part in *Bol. 258*.

CALIFORNIA

*"California Basement Production Possibilities," by William Ross Cabeen and Harold H. Sullwold, Jr. *Oil Weekly*, Vol. 122, No. 8 (Houston, July 22, 1946), pp. 17–25; 5 figs., 1 table.

*"Deep Zone Production from the Cymric Field, Kern County, California," by John H. Beach and Vernon L. King. *California Oil World*, Vol. 39, No. 13 (Los Angeles, July, 1946, 1st issue), pp. 3–5; 2 figs.

* "The First 25 Years at Signal Hill," by Richard Sneddon. *Petrol. Engineer*, Vol. 17, No. 11 (Dallas, Texas, July, 1946), pp. 52–62; 7 photographs.

CHINA

*"Mineral Resources of China," by V. C. Juan. *Econ. Geology*, Vol. 41, No. 4, Pt. 2 (Economic Geology Pub. Co., Urbana, Illinois, June, July, 1946), pp. 399–474; 13 maps, 53 tables. Price, $0.75.

COLOMBIA

*"Compilacion de los Estudios Geologicos Oficiales en Colombia," Tomo VI. *Servico Geologico Nacional*, Ministerio de Minas y Petroleos (Bogotá, 1945). A collection of many articles on various ore deposits, mineral resources, and geological studies in Colombia. 494 pp., 75 pls. (photographs, maps in color, and black-line drawings, text figs.). Approx. 6.625×9.5 inches. In Spanish.

*"Mapa Geologio General de la Republico de Colombia a Escala de 1:2,000,000 y Breve Explicacion," *ibid.*, Tomo VI, Anexo I. Geological map in 20 colors on a sheet 33.5×39.5 inches. Explanatory and descriptive text, 34 pp., 20 pls. (photographs).

*"Bibliografia Geologica, Geografica y Minera de Colombia," by Jose Royo y Gomez. *Ibid.*, Tomo VI, Anexo II. Annotated bibliography. 127 pp.

ENGLAND

*"An Outline of the Geology of Ashover, Derbyshire," by G. S. Sweeting. *Proc. Geologists' Association*, Vol. 57, Pt. 2 (Imperial College of Science and Technology, South Kensington, SW. 7, June 26, 1946), pp. 117–36; 1 fig., 2 photographs, 1 pl. (folded geological map). Describes the Carboniferous limestone and the Millstone grit in a structural dome where the economic products are lead, fluorspar, and barytes.

GENERAL

*"Operational Procedure for the Airborne Magnetometer," by Homer Jensen. *Oil and Gas Jour.*, Vol. 45, No. 10 (Tulsa, July 13, 1946), pp. 80–83; 4 figs.

*"The Development and Applications of Airborne Magnetometers in the U.S.S.R.," by A. A. Logachev. *Petroleum Engineer*, Vol. 17, No. 10 (Dallas, Texas, Reference Annual, 1946), pp. 211–18; 6 figs. Translation by H. E. Hawkes, U. S. Geol. Survey, from *Razvedka Nedr.*, Vol. 7, No. 51 (1937), pp. 34–37.

*"Geology Applied to Petroleum. Part 1, Petroleum in the Sedimentary Cycle," by Vincent C. Illing. *Oil Weekly*, Vol. 122, No. 7 (Houston, July 15, 1946), pp. 34–36, 42; 1 fig., 1 photograph.

*"Gas Reserves of the U. S.," by E. De Golyer. *Oil Weekly*, Vol. 122, No. 9 (Houston, July 29, 1946), pp. 62–65; 2 figs., 3 tables.

*"The Role of Bacteria in Oil Production," by J. V. Beck. *Producers Monthly*, Vol. 10, No. 9 (Bradford, Pennsylvania, July, 1946), pp. 29–31; 2 figs., 1 table.

*"Rate and Mass of Deep-Sea Sedimentation," by Ph. H. Kuenen. *Amer. Jour. Sci.*, Vol. 244, No. 8 (New Haven, Connecticut, August, 1946), pp. 563–72.

**Petroleum Discovery and Production.* 8-page brochure, 8.5×11 inches, in 2 colors; diarams showing exploration, drilling, and production methods. Amer. Petrol. Inst., 50 West 50th Street, New York 20, N. Y. (1946). Price, $0.10.

GERMANY

*"German Oil Industry," by B. Orchard Lisel. *Petroleum*, Vol. 9, No. 7 (July, 1946), pp. 160–61, 173; sketch map and statistics of drilling and production. Leonard Hill Ltd., 17 Stratford Place, London, W. 1, England. Annual subscription, 20 s., post free (abroad, 22 s. 6 d).

ILLINOIS

Geologic Map of Illinois, as of 1945. Size, 41×58 inches. Engraved in colors. Includes columnar sections for northern, western, central, and southern Illinois and 5 cross sections. Illinois State Geol. Survey, Urbana. Price, $0.35.

*"Flood Tide in Illinois," by Frederick Squires. *Producers Monthly*, Vol. 10, No. 9 (Bradford, Pennsylvania, July, 1946), pp. 10–19; 23 figs.

*"Silurian Invertebrate Fossils from Illinois in the Thomas A. Greene Memorial Museum at Milwaukee-Downer College," compiled by Katherine F. Greacen and John R. Ball. *Milwaukee-Downer College Bull.* (June, 1946). 61 pp.

KANSAS

*"Exploration for Oil and Gas in Western Kansas during 1945," by Walter A. Ver Wiebe. *Kansas Geol. Survey Bull. 62* (Lawrence, June, 1946). 112 pp., 31 figs., 41 tables.

MONTANA

*"Dating Sedimentation, Vulcanism, and Orogeny in Beartooth Mountain Region, Montana, by Heavy Minerals," by Marcellus H. Stow. *Bull. Geol. Soc. America*, Vol. 57, No. 7 (New York, July, 1946), pp. 675–86; 1 fig., 1 pl.

NETHERLANDS

The following is a partial list of titles from the "New Series of Publications in Geological-Paleontological Research in the Subsurface of the Netherlands" (*Uitkomsten van Nieuwe Geologisch-Palaeontologische Onderzoekingen van den Ondergrong van Nederland*), made under the direction of W. A. J. M. van Waterschoot van der Gracht, and W. J. Jongmans, P. Tesch, L. U. de Sitter, and collaborators, for the Netherlands Geological Survey (Mededeelingen van de Geologische Stichting, Ser. C). Copies may be obtained from the printer, Ernest van Aelst, Witmakerstraat 25, Maastricht; Geologisch Bureau voor het Nederlandsche Mijngebied, Akerstraat 86–88, Heerlen; or Afdeeling Geologische Kaart, Spaare 17, Haarlem, Holland.

*"Petrological Investigations of the Coal Measure Sediments of South Limburg (The Netherlands)," by N. Heertjes. II-2-No. 1 (1942). 85 pp., 2 folded pls. in pocket, 2 pls. of photomicrographs, 11 figs. In English. Price, f. 4.00.

*"Stratigraphy of the Oligocene-Miocene of the Netherland's According to the Foraminifera (Excepting South Limburg)," by A. Ten Dam and Th. Reinhold. V-No. 2 (1942). 106 pp., 10 pls. of Foraminifera; 7 folded tables in pocket; 10 text figs., line sketches. In Dutch and English. Price, f. 9.00.

*"Sedimentary Petrology of the Post-Carboniferous Sediments in Limburg (The Netherlands)," by J. E. Muller. II-2-No. 2 (1943). 78 pp., 18 tables, 3 folded pls. in pocket, text illus. In Dutch and English. Price, f. 6.75.

*"Coal-Petrographical Studies. Parallelization of the Merl, Muhlenbach, Steinknipp, and Finefrau Coal Seams of the Netherlands Mining District," by P. A. Hacquébard. III-2-No. 1 (1943). 129 pp., 3 pls. of photomicrographs; 9 folded pls. in color in pocket; many small text charts, 3 figs. In Dutch and English. Price, f. 11.25.

*"Oligocene Invertebrates of South-Limburg," by J. C. H. Albrecht and W. Valk. IV-1-No. 3 (1943). 163 pp., 27 pls. of fossils. In German. Price, f. 9.25.

*"Stratigraphy of the Netherland Paleocene and Eocene According to Foraminifera (Excepting South-Limburg)," by A. Ten Dam. V-No. 3 (1933). 142 pp., 6 pls. of fossils; charts, profiles, maps. In German. Price, f. 7.00.

*"Coal-Petrographical Studies. Parallelization of Coal Seams at Grauweck, Sentenweck, Rauschenwerk and Athwekr in the Netherlands Mining District," by A. L. F. J. Maurenbrecher. III-2-No. 2 (1944). 108 pp., 6 pls. (photographs of samples), 5 folded pls. in pocket, 7 charts, 8 figs., sketches. In Dutch and English. Price, f. 10.50.

*"Post-Carboniferous Tectonics of the South-Limburg Coal Mine District (The Netherlands)," by J. E. Muller. I-1-No. 2 (1945). 32 pp., 3 folded pls. in pocket; several figs. In Dutch and English. Price, f. 4.50.

*"Geology of the State Colliery Maurits Field," by A. J. Dikkers. I-1-No. 1 (1945). 88 pp., 7 folded pls. in pocket, 14 figs. In Dutch and English. Price, f. 8.50.

*"The Marine Fauna of the Carboniferous in the Netherlands," by L. Dorsman. IV-3-No. 3 (1945). 101 pp., 11 pls. of fossils, 10 tables, 3 figs. In English. Price, f. 11.50.

NORTH DAKOTA

*"Bibliography of the Geology and Natural Resources of North Dakota, 1814–1944," by Chrissie E. Budge. *North Dakota Research Foundation Bull. 1* (Bismarck, 1946). 214 pp.

OKLAHOMA

*"Anadarko Basin Prospects," by R. C. Tuttle. *Oil Weekly*, Vol. 122, No. 8 (Houston, July 22, 1946), pp. 37–42; 5 figs.

PACIFIC REGION

*"Some Tertiary Corallinaceae of the Malaysian Archipelago," by L. H. Lignac-Grutterink. *Verhandl. Geologisch-Mijnbouwkundig Genootschap voor Nederland en Kolonien*, Geol. Ser., Deel XIII ('s-Gravenhage, December, 1943), pp. 283–97; 1 fig., 2 pls. In English.

*"On the Petrological and Structural Character of the Pacific," by G. L. Smit Sibinga. *Ibid.*, pp. 335–54; 4 figs. In English.

*"Tertiary Corals from Sumba (East Indies)," by J. H. F. Umbgrove. *Ibid.*, pp. 393–98; 1 fig., 3 pls. In English.

QUEBEC

*"Cambrian and Early Ordovician Stratigraphy of the Lower-St. Lawrence Valley,"

by Franco Rasetti. *Bull. Geol. Soc. America*, Vol. 57, No. 7 (New York, July, 1946), pp. 687–706; 4 figs., 2 pls.

SCOTLAND

*"The Great Glen Fault," by William Quarrier Kennedy. *Quar. Jour. Geol. Soc. London*, Vol. 102, Pt. 1, No. 405 (Longmans, Green & Co., Ltd., 43 Albert Drive, S. W. 19, London, April 30, 1946), pp. 41–76; 1 pl., 8 figs. This dislocation has been regarded by most geologists as a normal or dip-slip fault with a predominant vertical downthrow toward the southeast. It is here suggested that it is in reality a lateral-slip or wrench fault with a horizontal displacement of 65 miles. The dislocation has characteristics unlike those of most normal faults, but similar to the great strike-slip shears of the California Coast Range. The Hercynian forces, to which the formation of the fault is ascribed, were in operation during Upper Old Red Sandstone or Lower Carboniferous time. Price for complete number, 10 shillings.

SOUTH AMERICA

*"Geologic Outline of South American Oil Fields," by Victor Oppenheim. *Pan Amer. Inst. Min. Eng. & Geol., U. S. Sec., Tech. Paper 4* (New York, 1946). 35 pp., 1 map. Copies available at Pan American Institute, 109 Brookside Drive, Kenwood, Chevy Chase, Maryland.

VENEZUELA

*"Maracaibo Basin is South America's Largest Producing Area," by Anne Newman Sutton. *World Petroleum*, Vol. 17, No. 7 (New York, July, 1946), pp. 28–31; 3 photographs, map, 3 tables.

WALES

*"The Harlech Dome, North of the Barmouth Estuary," by Charles Alfred Matley and Theodore Stacey Wilson. *Quar. Jour. Geol. Soc. London*, Vol. 102, Pt. 1, No. 405 (Longmans, Green & Co., Ltd., 43 Albert Drive, S. W. 19, London, April 30, 1946), pp. 1–40; 2 pls., 4 figs. The area is 150 square miles in extent, between the Barmouth Estuary and the Vale of Ffestiniog, and contains 10,000 feet of Cambrian rocks, including thick formations of grit. The igneous rocks are intrusive, Lower Paleozoic in age. The sediments have undergone low-grade metamorphism. The general structure is a broken anticlinorium. Faults are numerous. Price of complete number, 10 shillings.

DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Sedimentary Petrology* (Tulsa, Oklahoma), Vol. 16, No. 2, (August, 1946).

"A Study of Textural Changes in a Beach by Repeated Samplings," by Marshall Schalk.

"Weathered Gravels and Sands of Oregon and Washington," by Victor T. Allen and Robert L. Nichols

"Evidence of Texture on the Origin of the Cheltenham Fireclay of Missouri and Associated Shales," by W. D. Keller.

"A Comparison of the Physical Properties and Petrographic Characteristics of Some Limestones and Dolomites of Southeastern Minnesota," by Ernest H. Lathram and George A. Thiel.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 9 (SEPTEMBER, 1946), PP. 1597-1615

THE ASSOCIATION ROUND TABLE

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THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

CONSTITUTION[1]

ARTICLE I. NAME

This Association shall be called "The American Association of Petroleum Geologists," incorporated under the laws of Colorado.

ARTICLE II. OBJECT

The object of this Association is to promote the science of geology, especially as it relates to petroleum and natural gas; to promote the technology of petroleum and natural gas and to encourage improvements in the methods of exploring for and exploiting these substances; to foster the spirit of scientific research amongst its members; to disseminate facts relating to the geology and technology of petroleum and natural gas.

ARTICLE III. MEMBERSHIP

Members

SECTION 1. Any person engaged in the work of petroleum geology or in research pertaining to petroleum geology or technology is eligible to active membership, provided he is a graduate of an institution of collegiate standing, in which institution he has done his major work in geology, or in sciences fundamental to petroleum geology, and in addition has had the equivalent of three years' experience in petroleum geology or in the application of these other sciences to petroleum geology or to research in petroleum geology or technology; and provided further that in the case of an applicant for membership who has not had the required collegiate or university training, but whose standing in the profession is well recognized, he shall be admitted to membership when his application shall have been favorably and unanimously acted upon by the executive committee; and provided further that these requirements shall not be construed to exclude teachers and research workers in recognized institutions, whose work is of such character as in the opinion of the executive committee shall qualify them for membership.

Active members alone shall be known as members.

Life Members

SECTION 2. The executive committee may grant life membership to members who have paid their dues and are otherwise qualified.

Associates

SECTION 3. Any person having completed as much as thirty hours of geology (an hour shall here be interpreted as meaning as much as sixteen recitation or lecture periods of one hour each, or the equivalent in laboratory) in a reputable institution of collegiate or university standing, or who has done field work equivalent to this, is eligible to associate membership, provided at the time of his application for membership he shall be engaged in geological studies in an institution of collegiate or university standing, or shall be engaged in petroleum geology; and any person who is a graduate of an institution of collegiate standing in which he has done his major work in sciences fundamental to petroleum geology or petro-

[1] The constitution and by-laws were adopted 1918, and amended 1921, 1922, 1923, 1925, 1927, 1928, 1929, 1930, 1932, 1933, 1935, 1936, 1939, 1940, 1942, 1943, 1944, 1945, and 1946.

leum technology, and who has the equivalent of one year's experience in the application of his science to the study of petroleum geology, shall be eligible to associate membership, provided at the time of his application for membership he shall be engaged in investigations in the broader subject of petroleum geology and technology.

Associate members shall be known as associates.

Associates shall enjoy all the privileges of membership in the Association, save that they shall not hold office, sign applications for membership, or vote; neither shall they have the privilege of advertising their affiliation with the Association in professional cards or professional reports or otherwise.

The executive committee may advance to active membership, without the formality of application for such change, those associates who have, subsequent to election, fulfilled the requirements for active membership.

Election to Membership

SECTION 4. Every candidate for admission as a member or associate shall submit a formal application on an application form authorized by the executive committee, signed by him, and endorsed by not less than three members who are in good standing, stating his training and experience and such other facts as the executive committee shall from time to time prescribe. Provided the executive committee, after due consideration, shall judge that the applicant's qualifications meet the requirements of the constitution, they shall cause to be published in the *Bulletin* the applicant's name and the names of his sponsors. If after at least thirty days have elapsed since such publication, no reason is presented why the applicant should not be admitted, he shall be deemed eligible to membership or to associate membership, as the case may be, and shall be notified of his election.

With the notice of election shall be included a copy of the constitution and by-laws of the Association.

SECTION 5. An applicant for membership, on being notified of his election in writing, shall pay full membership dues for the current year and on making such payment shall be entitled to receive the entire *Bulletin* for that year. Unless payment of dues is made within thirty (30) days by those living within the continental United States and within ninety (90) days by those living elsewhere, after notice of election has been mailed, the executive committee may rescind the election of the applicant. Upon payment of dues, each applicant for membership shall be furnished with a membership card for the current year, and until such written notice and card are received, he shall in no way be considered a member of the Association.

Honorary Members

SECTION 6. The executive committee may from time to time elect as honorary members persons who have contributed distinguished service to the cause of petroleum geology. Honorary members shall not be required to pay dues.

SECTION 7. Each member and associate shall be guided by the highest standards of business ethics, personal honor, and professional conduct.

SECTION 8. Any member or associate who, after due investigation, is found guilty of violating any of the standards of conduct prescribed in Section 7 of this Article, may be admonished, suspended, allowed to resign, or dropped from membership in accordance with the procedure provided in the by-laws.

ARTICLE IV. OFFICERS AND THEIR DUTIES

Officers

SECTION 1. The officers of the Association shall be a president, a vice-president, a secretary-treasurer, and an editor. These, together with the past-president, shall constitute the executive committee and managers of the Association.

SECTION 2. The officers shall be elected annually from the Association at large by means of secret mailed ballot in the following manner. The nominating committee shall nominate one or more candidates for each office, and its nominations shall be published in the September *Bulletin*. Additional nominations may be made by written petition of fifty, or more, members in good standing received at Association headquarters not later than November 15. The executive committee shall then prepare a printed ballot, listing the candidates for each office, and one ballot shall be mailed to each member as soon after November 15 as possible. Ballots returned to Association headquarters on or before January 31 shall be placed as received in a locked ballot box and promptly after January 31 the ballot committee shall open the ballot box and count the ballots. Ballots of delinquent members shall not be counted. A majority of all votes cast for an office is necessary for election. If there are three or more nominees for any office, a preferential form of ballot shall be used. In case of a tie vote, the executive committee shall cast one additional deciding vote. Each candidate, when voted for as a candidate for the particular office for which he is nominated, shall be thereby automatically voted for as a candidate for the executive committee for one year, except that candidates for the presidency shall be automatically voted for as candidates for the executive committee for two years.

SECTION 3. No one shall hold the office of president for two consecutive years and no one shall hold any other office for more than two consecutive years except the editor who shall not hold office for more than six consecutive years.

Duties of Officers

SECTION 4. The president-shall be the presiding officer at all meetings of the Association, shall take cognizance of the acts of the Association and of its officers, shall appoint such committees as are required for the purposes of the Association, except the nominating committee, and shall delegate members to represent the Association. He may, at his option, serve on, and may be chairman of, any committee, except the nominating committee.

SECTION 5. The vice-president shall assume the office of president in case of a vacancy from any cause in that office and shall assume the duties of president in case of the absence or disability of the latter. If the past-president shall for any reason be unable to serve as a member of the executive committee, the president shall fill the vacancy by the appointment of the next available preceding past-president.

A vacancy or disability occurring in the office of vice-president, secretary-treasurer, or editor shall be filled by majority vote of the executive committee, either for the unexpired term or for the period of disability, as the committee may decide. In the case of a tie, the president shall cast the deciding vote.

SECTION 6. The secretary-treasurer shall assume the duties of president in case of the absence of both the president and vice-president. He shall have charge of the financial affairs of the Association and shall annually submit reports as secretary-treasurer covering the fiscal year. He shall receive all funds of the Association, and, under the direction of the executive committee, shall disburse all funds of the Association. He shall cause an audit to be prepared annually by a public accountant at the expense of the Association. He shall give a bond, and shall cause to be bonded all employees to whom authority may be delegated to handle Association funds. The amount of such bonds shall be set by the executive committee and the expense shall be borne by the Association. The funds of the Association shall be disbursed by check as authorized by the executive committee.

SECTION 7. The editor shall be in charge of editorial business, shall submit an annual report of such business, shall have authority to solicit papers and material for the *Bulletin* and for special publications, and, with the approval of the executive commmittee, may accept or reject material offered for publication. He may appoint associate, regional, and special editors.

SECTION 8. The officers shall assume the duties of their respective offices immediately after the annual meeting, which follows their election.

ARTICLE V. EXECUTIVE COMMITTEE—MEETINGS AND DUTIES

Executive Committee

SECTION 1. The executive committee shall consist of the president, past-president, vice-president, secretary-treasurer, and editor.

Meetings and Duties

SECTION 2. The executive committee shall meet immediately preceding the annual meeting and at the call of the president may hold meetings when and where thought advisable, to conduct the affairs of the Association. A joint meeting of the outgoing and incoming executive committees shall be held immediately after the close of the annual Association business meeting. Members of the executive committee may vote by proxy on matters which require a unanimous vote.

SECTION 3. The executive committee shall consider all nominations for membership and pass on the qualifications of the applicants; shall have control and management of the affairs and funds of the Association; shall determine the manner of publication and pass on the material presented for publication; shall designate the place of the annual meeting; shall appoint the nominating committee and its chairman; and shall be in charge of the annual election of officers and decide eligibility and other questions pertaining to the election. They are empowered to establish a business headquarters for the Association, and to employ such persons as are needed to conduct the business of the Association. They are empowered to accept, create, and maintain special funds for publication, research, and other purposes. They are empowered to make investments of both general and special funds of the Association. Trust funds may be created, giving to the trustees appointed for such purpose, such direction as to investments as seems desirable to the executive committee to accomplish any of its objects and purposes, but no such trust funds shall be created unless they are revocable upon ninety (90) days' notice.

ARTICLE VI. MEETINGS

The Association shall hold at least one stated meeting each year, which shall be the annual meeting. This meeting shall be held in March or April at a time and place designated by the executive committee. At this meeting the election of members shall be announced, the proceedings of the preceding meeting shall be read, Association business shall be transacted, scientific papers shall be read and discussed and officers for the ensuing year shall be announced.

ARTICLE VII. AMENDMENTS

Amendments to this constitution may be proposed by a resolution of the executive committee, by a constitutional committee appointed by the president, or in writing by any ten members of the Association. All such resolutions or proposals must be submitted at the annual meeting of the business committee of the Association as provided in the by-laws, and only the business committee shall make recommendations concerning proposed constitutional changes at the annual Association business meeting. If such recommendations by the business committee shall be favorably acted on at the annual Association business meeting, the secretary-treasurer shall arrange for a ballot of the membership by mail within thirty (30) days after said annual Association business meeting, and a majority vote of the ballots received within ninety (90) days of their mailing shall be sufficient to amend. The legality of all amendments must be determined by the executive committee prior to balloting.

BY-LAWS

ARTICLE I. DUES

SECTION 1. The fiscal year of the Association shall correspond with the calendar year.

SECTION 2. The annual dues of members of the Association shall be ten dollars ($10.00). The annual dues of associates for not to exceed three years after election shall be six dollars ($6.00); for the second three-year period eight dollars ($8.00); thereafter, the annual dues of such associates shall be ten dollars ($10.00). The annual dues are payable in advance on the first day of each calendar year. A bill shall be mailed to each member and associate before December first of each year, stating the amount of the annual dues and the penalty and conditions for default in payment. Members or associates who shall fail to pay their annual dues by January first shall not receive copies of the January *Bulletin* or succeeding *Bulletins*, nor shall they be privileged to buy Association special publications at prices made to the membership, until such arrears are met.

During any period in which the United States is actually engaged in war and for a period of one year thereafter, the executive committee may at its discretion suspend, reduce, or waive annual dues to members or associate members serving in the armed forces of the United States or any allied country, without otherwise affecting their membership, except that they shall not receive the *Bulletin* during a period for which no dues are paid.

SECTION 3. On the payment of two hundred dollars ($200.00) any member in good standing shall be declared a life member and thereafter shall not be required to pay annual dues. The funds derived from this source shall be placed in a permanent investment, the income from which shall be devoted to the same purposes as the regular dues.

ARTICLE II. RESIGNATION—SUSPENSION—EXPULSION

SECTION 1. Any member or associate may resign from the Association at any time. Such resignation shall be in writing and shall be accepted by the executive committee, subject to the payment of all outstanding dues and obligations of the resigning member or associate.

SECTION 2. Any member or associate who is more than a year delinquent (in arrears) in payment of dues shall be suspended from the Association. Any delinquent or suspended member or associate, at his own option, may request in writing that he be dropped from the Association and such request shall be granted by the executive committee. Any member or associate more than two years in arrears shall be dropped from the Association. The time of payment of delinquent dues for either one year or two years may be extended by unanimous vote of the executive committee.

SECTION 3. Any member or associate who resigns or is dropped under the provisions of Sections 1 and 2 of this article ceases to have any rights in the Association and ceases to incur further indebtedness to the Association.

SECTION 4. Any person who has ceased to be a member or associate under Section 1 or Section 2 of this article may be reinstated by unanimous vote of the executive committee subject to the payment of any outstanding dues and obligations which were incurred, prior to the date when he ceased to be a member or associate of the Association.

In the case of any member or associate who has been dropped between the dates of January 1, 1931, and January 1, 1936, for non-payment of dues and who shall apply for reinstatement, the executive committee is authorized, at its discretion, to accept the resignation of such member or associate effective at any date during such period of delinquency, provided, the member shall pay all indebtedness to the Association incurred prior to the date of such resignation including a proper proportion of annual dues as shall be fixed by the executive committee. Such member or associate shall not be entitled to receive the *Bulletin* for any period subsequent to the date when his resignation became effective and prior to his reinstatement.

SECTION 5. Charges of misconduct in violation of Section 7 of Article III of the constitution shall first be submitted in writing to the president of the Association by a member in good standing, in confidence, with a full statement of the evidence on which the charges are based. If in his judgment they merit further consideration, he shall appoint a committee to consist of three past-presidents of the Association, which shall examine into the charges. If in the judgment of said committee, the facts warrant, it shall prepare and file with the executive committee formal charges against the accused member or associate. As soon as may be after the receipt of such charges the executive committee shall fix a date and place for hearing thereupon, and shall give to the accused person notice thereof in writing, mailed to him by registered mail at his last-known post-office address not less than thirty (30) days before said date, accompanied by a copy of the charges, and a copy of this article.

SECTION 6. On the day fixed for the hearing, the accused person may appear before the executive committee, either in person or by an accredited representative; hear any witnesses who may be called in support of the charges; and, at his option, cross-examine the same, and hear any documentary evidence, including a statement from himself in writing. At his option, he may by letter waive personal hearing, and request the executive committee to adjudge the matter on the basis of a written statement of his defense, mailed to the committee before the date set for the hearing. After the conclusion of the hearing, or study of written defense submitted in lieu of a personal hearing, the executive committee shall consider and vote to approve or disapprove the charges. If the executive committee shall, by unanimous vote, declare the charges sustained, it may suspend the accused person from membership for a stated period, admonish him, allow him to resign, or expel him. Failure of the accused person to appear either in person or by an accredited representative shall not prevent the executive committee from proceeding with the trial.

SECTION 7. If the accused person shall not appear at the hearing nor waive his right thereto, and shall within three months after the date set for the hearing file with the executive committee an affidavit stating that he had not received notice of the charges against him in time to enable him to present his defense, the executive committee shall fix a date and place for a hearing not less than thirty days nor more than three months from the receipt of such affidavit, and shall immediately notify the accused person by registered mail of such date and place. Upon the rehearing, the proceedings shall be governed by the provisions of Section 6 of this article.

SECTION 8. Resignation of the accused person from membership in the Association, at any stage of the foregoing prescribed proceedings, shall automatically terminate the proceedings.

SECTION 9. The decision of the executive committee in all matters pertaining to the interpretation and execution of the provisions of Sections 5, 6, and 7 of this article shall be final.

ARTICLE III. PUBLICATIONS

SECTION 1. The proceedings of the annual meeting and the papers presented at such meetings shall be published at the discretion of the executive committee in the Association *Bulletin* or in such other form as the executive committee may decide best meets the needs of the membership of the Association.

SECTION 2. The payment of annual dues for any fiscal year entitles the member or associate to receive without further charge a copy of the *Bulletin* of the Association for that year.

SECTION 3. The executive committee may authorize the printing of special publications to be financed by the Association from its general, publication, or special funds and offered for sale to members and associates in good standing at not less than cost of publication and distribution.

ARTICLE IV. REGIONAL SECTIONS, TECHNICAL DIVISIONS, AND AFFILIATED SOCIETIES

SECTION 1. Regional sections of the Association may be established provided the members of such sections are members of the Association and shall perfect an organization and make application to the executive committee. The executive committee shall submit the application to a vote at a regular annual meeting, an affirmative vote of two-thirds of the members present and voting being necessary for the establishment of such a section; and provided that the Association may revoke the charter of any regional section by a vote of two-thirds of the members present and voting at a regular annual meeting.

SECTION 2. Technical divisions may be established, provided the members interested shall perfect an organization and make application to the executive committee. The executive committee shall submit the application to a vote at a regular meeting, an affirmative vote of two-thirds of the membership present and voting being necessary for the establishment of such a division. In like manner, the Association may dissolve a division by an affirmative vote of two-thirds of the members present and voting at any annual meeting. A technical division may have its own officers, and it may have its own constitution and by-laws provided that, in the opinion of the executive committee, these do not conflict with the constitution and by-laws of the Association. The executive committee shall be empowered to make arrangements with the officers of the division for the conduct of the business of the division. A division may admit to affiliate membership in the division specially qualified persons who are not eligible to membership in the Association. Technical divisions may affiliate with other scientific societies, with the approval of the executive committee.

SECTION 3. Subject to the affirmative vote of two-thirds of the membership present and voting at an annual meeting, and with legal advice, the executive committee may arrange for the affiliation with the Association of duly organized groups or societies, which by objects, aims, constitutions, by-laws, or practice are developing the study of geology or petroleum technology. In like manner and with like advice, the executive committee may arrange conditions for dissolution of such affiliations. Affiliation with the Association need not prevent affiliation with other scientific societies. Members of affiliated societies who are not members of the Association, shall not have the privilege of advertising their affiliation with the Association on professional cards or otherwise.

ARTICLE V. DISTRICT REPRESENTATIVES

The executive committee shall cause to be elected district representatives from districts which it shall define by a local geographic grouping of the membership. Such districts shall be redesignated and redefined by the executive committee as often as seems advisable. Each district shall be entitled to one representative for each seventy-five members, but this shall not deprive any designated district of at least one representative. The representatives so apportioned shall be chosen from the membership of the district by a written ballot arranged by the executive committee. They shall hold office for two years, their term of office expiring at the close of the annual meeting.

ARTICLE VI. COMMITTEES

Appointment and Tenure

SECTION 1. There shall be the following standing committees: business committee; research committee; committee on geologic names and correlations; committee on applications of geology; committee for publication; finance committee; committee on statistics of exploratory drilling; trustees of revolving publication fund; trustees of research fund; medal award committee; and distinguished lecture committee.

The president shall appoint all standing committees except the business committee and the medal award committee, for which provision is hereafter made. Members of all committees except the business committee shall serve for a three-year term, but in rotation, with one-third of the members being appointed each year. The president shall designate the chairmen, annually, shall have power to fill vacancies, and shall notify the members of the committees of their appointment. The president may designate one or more vice-chairmen annually.

In addition to the aforesaid standing committees, the executive committee shall appoint annually a nominating committee and its chairman, the president shall appoint annually a ballot committee, and annually or semiannually a resolutions committee, and such special committees as the executive committee may authorize. Special committees shall be appointed for a term of one year. The president shall designate the chairmen of such committees.

Business Committee

SECTION 2. The business committee shall act as a council and advisory board to the executive committee and the Association. This committee shall consist of the executive committee, not more than five members at large appointed annually by the president, two members elected by and from each technical division, and the district representatives. The president shall also appoint annually a chairman and a vice-chairman, but neither of these need be one of those otherwise constituting the business committee. The secretary-treasurer shall act as secretary of the business committee. If a district or technical representative is unable to be present at any meeting of the committee he may designate an alternate, who, in the case of a district representative, may or may not be a resident of the district he is asked to represent, and the alternate, on presentation of such a designation in writing, shall have the same powers and privileges as a regularly chosen representative. The business committee shall meet the day before the annual meeting at which all proposed changes in the constitution or by-laws shall be considered, all old and new business shall be discussed, and recommendations shall be voted for presentation at the annual meeting.

Research Committee

SECTION 3. The purpose of the research committee is the advancement of research, particularly within the field of petroleum geology. The committee shall consist of twenty-four members unless a different number is authorized by the executive committee.

Committee on Geologic Names and Correlations

SECTION 4. The purpose of the committee on geologic names and correlations is to lend assistance to authors on problems on stratigraphy and nomenclature and to advise the editor and executive committee in regard to the propriety of the use of stratigraphic names and correlations in papers submitted for publication by the Association. The committee shall consist of fifteen members unless a different number is authorized by the executive committee.

Committee on Applications of Geology

SECTION 5. The object of the committee on applications of geology is to advise and promote ways and means for informing the general public on all phases of geology particularly on the natural occurrence of oil and gas underground, the methods of searching for these substances, and the methods of exploiting them. The committee shall consist of twelve members unless a different number is authorized by the executive committee.

Committee for Publication

SECTION 6. The purpose of the committee for publication is to assist in securing desir-

able manuscripts for publication in the *Bulletin* or other publications of the Association. The committee may also assist in securing papers for delivery at the annual meetings. The committee shall consist of twenty-four members unless a different number is authorized by the executive committee.

Finance Committee

SECTION 7. The finance committee shall act as financial advisers to the executive committee. The committee shall consist of three members. If a member of the finance committee should be elected to the executive committee he shall resign from the finance committee and the president shall appoint a member of the Association to complete his unexpired term.

Trustees of Revolving Publication Fund

SECTION 8. Before any publication project shall be undertaken with the use of the revolving publication fund the approval of the trustees and the executive committee must be secured. There shall be three trustees. If a trustee should be elected to the executive committee he shall resign as a trustee and the president shall appoint a member of the Association to complete his unexpired term.

Trustees of Research Fund

SECTION 9. Before any research work may be undertaken with the use of money from the research fund, the approval of the trustees and the executive committee shall be secured. There shall be three trustees. If a trustee shall be elected to the executive committee he shall resign as a trustee and the president shall appoint a member of the Association to complete his unexpired term.

Resolutions Committee

SECTION 10. The resolutions committee shall be charged with the duty of presenting at the annual and semi-annual meetings resolutions expressing the Association's appreciation and thanks to those who have worked and contributed to the success of the meetings.

Medal Award Committee

SECTION 11. The purpose of the committee shall be to choose recipients for all medals or other awards which may be established by the executive committee. The committee shall consist of nine members and three ex-officio members. The nine members of the original committee shall be appointed by the president, three of whom shall serve for three years, three for two years, and three for one year. One of each of the groups appointed for the different lengths of time shall be a former president of the Association. Each incoming president shall thereafter appoint three members of the committee to serve for three years, one of which shall be a former president of the Association. Vacancies on the committee due to resignation or other causes shall be immediately filled by the president. The ex-officio members shall be: (1) the president of the Association, (2) the president of the Society of Exploration Geophysicists, (3) the president of the Society of Economic Paleontologists and Mineralogists. The president of the Association shall be the chairman of the committee, unless he shall, at his election, name a chairman to serve for one year.

Committee on Statistics of Exploratory Drilling

SECTION 12. The function of the committee on statistics of exploratory drilling shall be to assemble and compile statistics on the methods used to locate exploratory wells and on the results of exploratory drilling for oil and gas, and annually to submit for publication in the *Bulletin* a report summarizing and analyzing these data. This committee shall con-

sist of twenty-four members unless a different number is authorized by the executive committee.

Distinguished Lecture Committee

SECTION 13. The purpose of the distinguished lecture committee is to arrange, conduct, and manage a series of self-sustaining, non-profit lecture tours among affiliated societies and Association sections by outstanding speakers on timely subjects. The committee shall consist of seven members unless a different number is authorized by the executive committee.

Nominating Committee

SECTION 14. The purpose of the nominating committee is to nominate candidates for the Association offices as provided in the constitution. The committee shall consist of a chairman and four other members appointed by the executive committee to serve one year. At least two members of the nominating committees shall be past officers of the Association.

Ballot Committee

SECTION 15. The function of the ballot committee is to count the ballots received in the regular annual election and to report the final results to the president. A preferential form of ballot shall be counted in the following manner. The ballot committee shall count first-choice votes only. If no candidate receives a majority, the candidate with the fewest votes shall be eliminated and the second choice on his ballots shall be counted as first choice for the remaining candidates. The committee shall continue this procedure until one candidate has a majority.

ARTICLE VII. AMENDMENTS

These by-laws may be amended by vote of three-fourths of the members present and voting at any annual meeting, provided that such changes shall have been recommended to the meeting by the business committee and provided that their legality shall be determined by the executive committee prior to publication.

REPORT OF NOMINATING COMMITTEE

The Executive Committee
Earl B. Noble, chairman

Tulsa, Oklahoma, August 10, 1946

In accordance with Art. IV, Sec. 2, of the Constitution, as amended by mail ballot on July 29, and as hereafter quoted in full, your nominating committee herewith reports that it has selected the following slate of candidates to be submitted to the members of the Association. Each nominee has expressed his willingness to serve.

For President—CARROLL E. DOBBIN, U. S. Geological Survey, Denver, Colorado
For Vice-President—GEORGE S. BUCHANAN, Sohio Petroleum Corporation, Houston, Texas
For Secretary-Treasurer—J. V. HOWELL, Philtower Building, Tulsa, Oklahoma
For Editor—CLARENCE L. MOODY, The Ohio Oil Company, Shreveport, Louisiana

Respectfully submitted,

FRANK R. CLARK, *chairman*
ARTHUR E. BRAINERD
A. I. LEVORSEN
HUGH D. MISER
ROY R. MORSE

(From Constitution, Amended, July 29, 1946)

ARTICLE IV. OFFICERS AND THEIR DUTIES

SECTION 2. The officers shall be elected annually from the Association at large by means of secret mailed ballot in the following manner. The nominating committee shall nominate one or more candidates for each office, and its nominations shall be published in the September *Bulletin*. Additional nominations may be made by written petition of fifty, or more, members in good standing received at Association headquarters not later than November 15. The executive committee shall then prepare a printed ballot, listing the candidates for each office, and one ballot shall be mailed to each member as soon after November 15 as possible. Ballots returned to Association headquarters on or before January 31 shall be placed as received in a locked ballot box and promptly after January 31 the ballot committee shall open the ballot box and count the ballots. Ballots of delinquent members shall not be counted. A majority of all votes cast for an office is necessary for election. If there are three or more nominees for any office, a preferential form of ballot shall be used. In case of a tie vote, the executive committee shall cast one additional deciding vote. Each candidate, when voted for as a candidate for the particular office for which he is nominated, shall be thereby automatically voted for as candidate for the executive committee for one year, except that candidates for the presidency shall be automatically voted for as candidates for the executive committee for two years.

The attention of the members is directed particularly to the provision that "ADDITIONAL NOMINATIONS MAY BE MADE BY WRITTEN PETITION OF FIFTY, OR MORE, MEMBERS IN GOOD STANDING RECEIVED AT ASSOCIATION HEADQUARTERS NOT LATER THAN NOVEMBER 15." Any such petitions should be addressed to Edward A. Koester, Secretary-Treasurer, Box 979, Tulsa 1, Oklahoma, and should be sent in plenty of time to be received in Tulsa not later than November 15.

SUPPLEMENTARY MEMBERSHIP LIST, SEPTEMBER 1, 1946

Members	154
‖Associates	122
Total additions since publication of list in March *Bulletin*	276

‖Abbott, Earl O., Texon Oil & Land Co., 1710 Fair Bldg., Fort Worth, Tex.
Allen, John Eliot, 3925 N. E. Couch St., Portland, Ore.
‖Ammon, Walter Lamm, Stanolind Oil & Gas Co., Wichita Falls, Tex.
‖Anderson, Payton Victor, Humble Oil & Refining Co., 1405 Canal Bldg., New Orleans, La.
Anderson, Robert van Vleck, Department of Geology, Stanford University, Calif.
Arnold, Kingsland, Magnolia Petroleum Co., Box 900, Dallas, Tex.
Aston, Charles Albert, Jr., consulting, 207 Ward Bldg., Artesia, N. Mex.
‖Aycardo, Man Matthew, Jr., International Engineering Co., Soriano Bldg., Manila, P. I.
Bainton, Jack Douglas, Standard Oil Co. of California, Taft, Calif.
‖Baker, John Seaward, Shell Oil Co., Inc., Box 267, Alamogordo, N. Mex.
‖Baldwin, Ewart Merlin, Oregon Department of Geology, 702 Woodlark Bldg., Portland, Ore.
‖Bannahan, Annabelle Richardson, Rt. 12, Box 772, Houston, Tex.
‖Barkell, Clifford Abbott, Shell Oil Co., Inc., Box 720, Casper, Wyo.
‖Barker, William Kilmer, 914 Eighteenth St., Santa Monica, Calif.
Barksdale, Julian D., Department of Geology, University of Washington, Seattle, Wash.
Baumgarten, Frederick Augustus, Jr., Union Sulphur Co., Inc., Sulphur, La.
‖Baxter, George William, Trinidad Petroleum Development Co., Ltd., Palo Seco, Trinidad, B. W. I.
Bean, Beryl Kenneth, Gulf Refining Co., Mattoon, Ill.
Beer, George William, U. S. Geological Survey, Box 1827, Great Falls, Mont.
Bell, Clifton L., consulting, Perryton, Tex.
‖Bell, Ruth Eleanor, Skelly Oil Co., 510 Petroleum Bldg., Wichita, Kan.
Bench, Bernard Mayes, consulting, 1244 Holly St., Denver, Colo.
Berry, Harry Louis, Manahan Oil Co., National Bank of Tulsa Bldg., Tulsa, Okla.
‖Bertram, Alexander Carl, c/o John O. Harmon, Houston, Tex.

Binkley, William G., Superior Oil Co., Taft, Calif.
‖Blackstone, Thomas Warner, Gulf Oil Corp., Houston, Tex.
Bohdanowicz, Charles, Geological Survey of Poland, Krakow, Poland
Bowen, Gilbert Todd, Standard Oil Co. of Texas, Sherman, Tex.
‖Brinker, Willard Franklin, Cities Service Oil Co., Box 149, Mt. Pleasant, Mich.
‖Brinnon, William B., Magnolia Petroleum Co., Box 608, Lovington, N. Mex.
Brookings, Henry Nason Kinney, Phillips Petroleum Co., Shreveport, La.
Broussard, Charles Hugh, Independent Exploration Co., 901 Esperson Bldg., Houston, Tex.
Brown, Jack Harvey, Shell Oil Co., Inc., 1009 Central Bldg., Wichita, Kan.
Browning, John Mackintosh, International Ecuadorean Petroleum Co., Casilla 803, Guayaquil, Ecuador, S. A.
Burg, Kenneth Edwin, Stanolind Oil & Gas Co., Box 591, Tulsa, Okla.
‖Butcher, William Sherman, Woods Hole Oceanographic Institution, Woods Hole, Mass.
Cabeen, William Ross, consulting, 3421 N. Knoll Dr., Los Angeles, Calif.
Calvert, Mont Granderson, Jr., Humble Oil & Refining Co., 1405 Canal Bldg., New Orleans, La.
‖Capen, Maxwell Gary, Superior Oil Co., 313 Sill Bldg., Bakersfield, Calif.
Carlisle, Frederick Macklin, Internatl. Cementers, Box 2017, Terminal Annex, Los Angeles, Calif.
‖Chamberlain, Virgil Ralph, Union Oil Co. of California, Box 1696, Billings, Mont.
Chapman, Guy Edgar, Chapman Oil Co., Taylor Bldg., Mt. Pleasant, Mich.
‖Chata, Abdou Ali, Standard Oil Co. of Egypt, 22 Kasr el Nil, Cairo, Egypt
Chickering, Wallace Wylie, Oklahoma Natural Gas Co., 624 S. Boston, Tulsa, Okla.
Childs, Orlo E., Department of Geology, Colgate University, Hamilton, N. Y.
Church, Harry Victor, Jr., Shell Oil Co., Inc., Box 720, Casper, Wyo.
‖Cole, Mary Jane, Magnolia Petroleum Co., Box 1828, Oklahoma City, Okla.
‖Colson, William Edward, Tide Water Associated Oil Co., Box 1008, Corpus Christi, Tex.
Condon, James Carl, Anderson-Prichard Oil Corp., Orpheum Bldg., Wichita, Kan.
‖Cook, Paul Chronical, Keystone Exploration Co., 2813 Westheimer Rd., Houston, Tex.
Cox, William Edgerton, Humble Oil & Refining Co., Midland, Tex.
‖Crain, Hugh F., State Geological Survey, University of Kansas, Lawrence, Kan.
Crawford, Weldon L., Petty Geophysical Engineering Co., Box 2061, San Antonio, Tex.
Crichton, Jack Alston, DeGolyer & MacNaughton, 1000 Continental Bldg., Dallas, Tex.
Crider, Hugh Dixon, Muskegon Development Co., 432 Lyman Bldg., Muskegon, Mich.
‖Crump, J. G. H., Southwest Gas Producing Co., Inc., Ouachita National Bank Bldg., Monroe, La.
‖Curtis, Bruce Franklin, Continental Oil Co., Denver, Colo.
‖Curtis, Garniss Hearfield, 934 S. Forty-fifth St., Richmond, Calif.
‖Dady, William George, Stanolind Oil & Gas Co., Box 40, Casper, Wyo.
Damesin, Leopold Constant Frederic, Iraq Petroleum Co., Ltd., Box 309, Haifa, Palestine
‖Davis, Howard Eugene, Jr., Honolulu Oil Corp., Petroleum Bldg., Midland, Tex.
Davison, Wayne Corey, consulting, 607 Esperson Bldg., Houston, Tex.
Dawson, Lester Raymond, Jr., independent, 3770 Nottingham, Houston, Tex.
‖Deisenroth, Malcolm, Jr., Ashland Oil & Ref. Co., 308 Natl. Bank of Tulsa Bldg., Tulsa, Okla.
de Lima, Plinio, Instituto Geografico e Geologico, Sao Paulo, Brazil, S. A.
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‖Wood, Mary C., Tide Water Associated Oil Co., Houston, Tex.
Woodman, Kermit Thomas, Sohio Petroleum Co., 514 Bitting Bldg., Wichita, Kan.
Yoakam, Harlan Hunter, Plymouth Oil Co., Box 712, Sinton, Tex.
Young, John Chew, Conservation Committee of California Oil Producers, Los Angeles, Calif.
Zirbel, Nicholas Newton, Independent Exploration Co., 901 Esperson Bldg., Houston, Tex.

FALL MEETING, BILOXI, MISSISSIPPI, OCTOBER 24 AND 25, 1946

A mid-year meeting of the Association, sponsored by the Mississippi Geological Society, will be held at Biloxi, Mississippi, with the Buena Vista Hotel as headquarters.

Morning and afternoon technical sessions on October 24 and 25 will be devoted to the presentation of papers covering the stratigraphy and geology of the southeastern United States and the geology of some of the typical oil fields in the area.

Although the Buena Vista Hotel can not accommodate the entire attendance anticipated, all requests for reservations should be addressed directly to the Buena Vista which will handle the transfer of reservations to the White House, Tivoli, and the Biloxi hotels. Each of these is located within a one-mile radius of the headquarters hotel.

Registration will begin at noon Wednesday, October 23, the registration fee to be $2.50.

The only planned entertainment is to be a banquet on the night of October 24 at which president Noble will discuss briefly Association affairs. No official entertainment is planned for wives; however, they are cordially invited to attend.

The regional and field papers to be presented are here listed.

Regional Papers

Historical Notes on the Geology of Mississippi, by Urban B. Hughes, consulting geologist
Paleozoics, by Frederic F. Mellen, consulting geologist
Surface Occurrence of Cretaceous Beds in the Southeastern States, by Watson H. Monroe, United States Geological Survey
Subsurface Occurrence of Cretaceous Beds in Mississippi, by speaker to be selected
Tertiary, Quaternary and Recent Sediments of Mississippi and Adjacent Areas, by Grover Murray Jr., Magnolia Petroleum Company
Formation of Evaporites under Marine Evaporation Conditions, by Paul Weaver, Gulf Oil Corporation
Mesozoic Igneous Rocks of the Northern Gulf Coastal Plain, by C. L. Moody, Ohio Oil Company
Regional Geology of Northeast Louisiana and Southeast Arkansas, by speaker to be selected
Surface Tertiary Stratigraphy of Southern Alabama and Western Georgia (tentative), by F. Stearns MacNeil, United States Geological Survey
Geology of Northern Florida and Southern Georgia, by D. J. Munroe, Sun Oil Company
Geology of Peninsular Florida and the Sunniland Field, Collier County, Florida, by E. D. Pressler, Humble Oil and Refining Company
Status of Micropaleontology in the Eastern Gulf Region (tentative), by H. V. Howe, Dean of School of Arts and Sciences, Louisiana State University

Field Papers

Gilbertown Field, Choctaw County, Alabama, by Nathan C. Surber, Carter Oil Company
Delhi and Big Creek Fields, Richland Parish, Louisiana, by A. M. Lloyd, Sun Oil Company
Cranfield Field, Adams and Franklin Counties, Mississippi, by George Zebal, California Company
Heidelberg Field, Jasper County, Mississippi, by Tom McGlothlin, Gulf Refining Company
Tinsley Field, Yazoo County, Mississippi, by F. R. Schroeder and J. B. Storey, Union Producing Company

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MID-CONTINENT REGIONAL MEETING, WICHITA, KANSAS, JANUARY 16–17, 1947

At the invitation of the Kansas Geological Society, Harold O. Smedley, president, and Francis E. Mettner, secretary-treasurer, the Association will hold a Mid-Continent regional meeting at the Broadview Hotel, Wichita, Kansas, January 16 and 17, 1947. The program will feature "Exceptional Oil Fields" and "Possibilities of the Mid-Continent Region." E. C. Moncrief is general chairman and Edward A. Koester is chairman of the technical program.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 9 (SEPTEMBER, 1946), P. 1616

MEMORIAL

FRED BURCHARD ELY

(1883–1946)

The death of Fred B. Ely on March 28, 1946, as a result of a heart attack was a shock to his many friends in the oil and mining industries. For the last ten years or more, Ely's continuous and cheerful efforts in behalf of operation of the New York Section of the American Institute of Mining and Metallurgical Engineers and recently of the Eastern Section of the American Association of Petroleum Geologists served to widen an already large circle of sincere friends. As a consultant in the New York office of H. J. Wasson, his professional activities and interests had a wide scope.

Fred was born in Hoosick Falls, New York, in 1883. After graduation from Harvard in 1904, his professional career was devoted to mining engineering work in the western states, Canada, Mexico, and Alaska, until he entered military service in 1918. His postwar career was largely concerned with petroleum geology, petroleum engineering, and the appraisal of oil- and gas-producing properties. As petroleum geologist for the Standard Oil Company (New Jersey), he undertook geological work in many countries. During the seven-year period, 1920–1927, he worked in Mexico, Venezuela, and other countries. Since 1927, Fred maintained headquarters in New York City in the capacity of a consultant, working principally on oil and gas production and valuation problems.

Except among his closest associates, Ely was best known for his untiring work in the New York Section of the A.I.M.E., which he served well for several years as secretary, more recently having been elected vice-chairman of the executive committee. In the development of the Eastern Section of the A.A.P.G., his counsel was of particular value. In addition to his activities in these organizations, he likewise was an active member in New York of the Harvard Club, the Explorers Club, and the Mining Club. His later years were abundant with professional and quasi-social contacts which enriched the outlook of his associates.

Fred is survived by a daughter, Miss Ann Ely, two sisters, and a brother.

GAIL F. MOULTON

NEW YORK CITY
July 19, 1946

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 9 (SEPTEMBER, 1946), PP. 1617-1620

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The resignation of HAROLD W. HOOTS as chief geologist of the Richfield Oil Corporation became effective on June 15, although completion of special assignments for Richfield required his attention until August 1. On that date he entered into private consulting practice as an independent geologist and he will devote his attention primarily to problems relating to petroleum exploration. Temporary office quarters are located at 555 South Flower Street, Los Angeles 13, California. After receiving the degree of Ph.D. at Stanford University in 1925, Hoots continued his work with the United States Geological Survey through 1926. He was administrative and division geologist with the Union Oil Company from 1928 to 1937 when he left that company to become chief of the new geological department of the Richfield.

DOROTHY JUNG ECHOLS was recently employed by the Pond Fork Oil and Gas Company of Charleston, West Virginia, as consulting geologist. Her address is Box 67, Florissant, Missouri.

Lieutenant Colonel WILBUR B. SHERMAN recently returned from the Pacific and is now out of military service, back with Superior Oil Company at Bakersfield, California.

Lieutenant (j.g.) R. F. NEAL was discharged from the Navy on May 31 at Camp Wallace, Texas, and is employed as a geologist by the Benedum-Trees Oil Company, Houston.

CARL A. MOORE, for several years with the Carter Oil Company, has accepted a position with the Oklahoma Geological Survey, at Norman, as assistant geologist. In addition he will be on the staff of the School of Geology at the University of Oklahoma.

PARKE A. DICKEY, recently with the Quaker State Oil Refining Corporation, Bradford, Pennsylvania, is in the employ of the Carter Oil Company, Tulsa, Oklahoma, in the geological work of the Carter's Research Laboratory.

JOSEPH H. SINCLAIR, consulting geologist of New York City, died on May 24.

CLARK MILLISON, consulting geologist of Tulsa, Oklahoma, was a visiting instructor at the summer session of Colorado College, at Colorado Springs, Colorado.

THEODORE G. GLASS has resigned his position as district geologist in the Amarillo district of the Sinclair Prairie Oil Company, and has accepted the position of division manager with the Eason Oil Company at Mt. Vernon, Illinois.

J. C. BARCKLOW, formerly mid-continent sales manager and research geologist with the Lane-Wells Company at Oklahoma City, has resigned to open an office as consulting geologist at Ada, Oklahoma.

DONALD DUDLEY HUGHES died at Ferndale, California, July 23, at the age of 52 years. Hughes had been engaged in the private practice of geology and paleontology since 1939. Prior to his independent consulting work, he had been micropaleontologist for the Texas Company and the Marland Oil Company in California.

JAMES I. CULBERT, recently with the Stanolind Oil and Gas Company as a petroleum engineer, has accepted a position as associate professor of geology and geography at Arizona State College, Tempe, Arizona.

ELISABETH STILES, of Hamilton, Texas, has resigned as business manager of the Society of Exploration Geophysicists, and is succeeded by COLIN C. CAMPBELL who has opened the S.E.G. headquarters office in the Ritz Building, Tulsa, Oklahoma.

GEORGE E. WAGONER, assistant chief geophysicist in charge of domestic geophysical operations of the Carter Oil Company, has been appointed exploration manager in the southern division of the company. He has moved from Tulsa, Oklahoma, to Shreveport, Louisiana.

FRED E. NEUMANN is associate professor of geology at Chico State College, Chico, California.

CHARLES J. HOKE, formerly with the Phillips Petroleum Company at Shreveport, Louisiana, has resigned to accept a position with C. H. Murphy, Jr., at El Dorado, Arkansas.

LAURENCE L. SLOSS, associate professor of geology, has accepted an appointment as lecturer in paleontology at Northwestern University and has resigned from the Montana School of Mines. During the late summer and fall, he will be doing consulting work in petroleum geology in eastern Montana and Wyoming and will be in residence at Northwestern for the winter and spring quarters.

The Corpus Christi (Texas) Geological Society has elected the following officers: president, W. E. GREENMAN, Texas Company; vice-president, DALE L. BENSON, Sinclair Prairie Oil Company; secretary-treasurer, O. G. MCCLAIN (re-elected), consultant, 224 Nixon Building.

CHARLES A. STEEN, formerly with the Socony-Vacuum Oil Company in Peru, is now employed by the Stanolind Oil and Gas Company as field geologist with headquarters in Houston, Texas.

DONALD F. SANDIFER has left the Transwestern Oil Company and is now in charge of the geological department for the Anderson-Prichard Oil Corporation in the South Texas district at San Antonio.

CHARLES C. BATES, formerly with the Carter Oil Company, has recently returned from the Crossroads Operation. He participated in the preliminary oceanographic and geologic surveys of Bikini and several other atolls. At present he is an associate oceanographer with the newly formed Oceanographic Division of the Hydrographic Office, United States Navy.

ARTHUR BEVAN, State geologist of Virginia, has been appointed chairman of The Division of Geology and Geography of the National Research Council, for the 3-year term from July 1, 1946. He succeeds WILLIAM W. RUBEY, of the United States Geological Survey, whose term had expired.

GERALD E. EDDY succeeds R. A. SMITH, retired, as State geologist of Michigan. He has been in the mining division of the Survey.

W. EARLE SHAMBLIN, recently with the Devonian Oil Company, is district geologist with the Deep Rock Oil Corporation at Shreveport, Louisiana.

CECIL G. LALICKER, professor of geology at the University of Oklahoma, has joined the faculty of the Colorado School of Mines at Golden.

W. D. HENDERSON and J. GUY MCMILLIAN have organized a new firm of independent

oil operators at Midland, Texas. Henderson was recently district geologist for the Phillips Petroleum Company for West Texas and New Mexico.

The Midland Sample Library of JOHN M. HILLS and E. RUSSELL LLOYD, Midland, Texas, has grown to more than 4 million samples since it was established within the present year. The establishment depends on oil companies and individual operators for samples to be stored and indexed. The service is available on a subscription basis.

CLAUDE P. PARSONS, formerly vice-president of Halliburton Oil Well Cementing Company, has been appointed vice-president and special sales representative of Hughes Tool Company, Houston, Texas.

CAMPBELL OSBORN, formerly of Ponca City and Tulsa, Oklahoma, and recently at Washington, D. C., is in charge of the chemical and petroleum industries of Japan under General MacArthur.

JOHN J. RUPNIK has resigned from the United Geophysical Company and is now with the Sun Oil Company at Beaumont, Texas.

NEWELL M. WILDER has been released from the Army with the grade of Major. He is manager of the land and geological department of Southern Petroleum Exploration, Inc., Radio Building, Wichita Falls, Texas.

F. P. SCHWEERS has changed his connection from The Texas Company to the Samedan Oil Corporation, Ardmore, Oklahoma.

J. R. SCHWABROW has been appointed supervisor of oil and gas operations, northwestern region, United States Geological Survey, Casper, Wyoming, succeeding ERNEST A. HANSON who resigned December 7, 1945.

S. A. LYNCH, former head of the geology department of the North Texas Agricultural College, Arlington, Texas, and geologist with DeGolyer and MacNaughton, Dallas, has been named to head the reorganized geology department of Texas A. and M. College, College Station, Texas.

RAYMOND M. THOMPSON has returned from the Navy and is with the United States Geological Survey, Science Hall, University of Wyoming, Laramie.

R. VAN A. MILLS has retired from the Continental Oil Company, and may be addresed at 130 Whiteworth Avenue, Ponca City, Oklahoma.

Under leadership of S. H. KNIGHT and H. D. THOMAS of the University of Wyoming, J. D. LOVE and T. F. STIPP of the U. S. Geological Survey, and R. L. SIELAFF of the Sinclair Wyoming Oil Company, the Wyoming Geological Association recently sponsored its first annual field trip. Starting at Casper, the itinerary included Wheatland, oil fields of the Laramie basin, outcrops along the Laramie Mountains, Rawlins, and the Lost Soldier and Wertz Oil fields.

WILLIAM E. HUMPHREY has given up his position with The Texas Petroleum Company, Buenos Aires, Argentina, and is returning to the states. His address is 610 Park Boulevard, Austin 22, Texas.

WILLIAM C. RASMUSSEN has resigned from the U. S. Geological Survey staff, effective September 1, 1946, to become associate professor of geology at A. and M. College of Texas.

E. A. WALLSTROM, superintendent of production for the Gulf Oil Corporation at Fort

Worth, Texas, has resigned to enter independent work. He is succeeded by F. E. HATFIELD, who was recently with the Mene Grande Oil Company in Venezuela.

PAUL FUENNING has joined Geophoto Services, Inc., 110 West 13th Avenue, Denver, Colorado. Fuenning was a Photographic Intelligence Officer in the Navy and was recently doing post-graduate work in geology at the University of Chicago.

PAUL M. JAMESON, recently with the Tide Water Associated Oil Company, is in the geological department of the Gulf Oil Corporation, Tulsa, Oklahoma.

PAN-AMERICAN CONGRESS OF MINING ENGINEERING AND GEOLOGY

The Second Pan-American Congress of Mining Engineering and Geology will be held this October in Rio de Janeiro, Brazil. A series of five field trips will be offered concurrently, October 5–13: (1) Charcoal iron production and iron ore exportation; (2) Gold, manganese, quartz, and Minas Gerais Algonquian formations; (3) Coals of South Brazil; (4) Bauxite, zircon, Sao Paulo's metallurgical industries, Mogi das Cruzes, charcoal iron production, Volta Redonda's steel mill; (5) Geology of South Brazil's Gondwana regions.

Major C. HARRISON COOPER has been discharged from the Army after 5½ years of active duty, including 30 months in the Pacific as a field artillery officer with the 7th Infantry Division. Prior to the war he was district geologist in Kansas for the Indian Territory Illuminating Oil and Gas Company. Now district geologist in Oklahoma and Kansas for the British American Oil Producing Company, his address is 2407 First National Building, Oklahoma City, Oklahoma.

LLOYD S. PARKER, formerly with the Texas Pacific Coal and Oil Company, Shreveport, Louisiana, is now a firm member of Al and Lloyd Parker Company, Box 199, San Benito, Texas.

S. N. DAVIESS has resigned from the U. S. Geological Survey to accept a position with the Gulf Oil Corporation. His address is Cia. Petrolera Eureka, S. A., Calle 23, entre 2 y 4, No. 956, Vedado, Habana, Cuba.

L. W. LEROY, former assistant professor of geology, Colorado School of Mines, is now in charge of the geological subsurface laboratory for Richmond Exploration Company, Maracaibo, Venezuela.

AMENDMENTS TO CONSTITUTION AND BY-LAWS

By vote of the Association in annual meeting at Chicago, April 4, and by mail ballot on July 29, the proposed amendments to the constitution and by-laws as published in the report of the business committee on pages 757–760 of the May *Bulletin* (Vol. 30, No. 5) have been adopted.

Code of ethics.—The old detailed code of ethics is replaced by a brief simplified code stated as Section 7 of Article III of the constitution. The amendments were adopted: For, 1,787; Against, 54.

"SECTION 7. Each member and associate shall be guided by the highest standards of business, ethics, personal honor, and professional conduct."

Method of election of officers.—A new method of election of officers has been adopted (For; 1,636; Against, 206), whereby every member in good standing has an opportunity to vote by mailed ballot. A nominating committee appointed by the executive committee proposes a slate of officers which is published in the *Bulletin*, after which any group of 50 members in good standing may make additional nominations. All nominees are listed on the printed ballot.

New constitution and by-laws.—The complete constitution and by-laws, as now amended, are published in this issue of the *Bulletin*.

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1024 Continental Oil Building

Luncheons every Friday noon, Cosmopolitan Hotel. Evening dinner (6:15) and program (7:30) first Monday each month or by announcement, Cosmopolitan Hotel.

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Vice-President - - - - - - - E. E. Rehn
Sohio Petroleum Company
Box 537, Mt. Vernon

Secretary-Treasurer - - - - John B. Patton
Magnolia Petroleum Company
Box 535, Mt. Vernon

Meetings will be announced.

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Box 841

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The California Company

Vice-President - - - - - - - Walter B. Jones
Geological Survey of Alabama

Secretary-Treasurer - - - - - - H. A. Sellin
Magnolia Petroleum Company

Meetings will be announced. Visiting geologists and friends are welcome.

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INDIANA-KENTUCKY GEOLOGICAL SOCIETY

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Gulf Refining Company, Box 774

Vice-President - - - - - - J. Albert Brown
Sohio Petroleum Co.
Owensboro, Kentucky

Secretary-Treasurer - - - - - F. H. Latimer
Sun Oil Company
Evansville, Ind.

Meetings will be announced.

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WICHITA, KANSAS

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Skelly Oil Company
Vice-President - - - - - - Paul A. Harper
Cities Service Oil Company
Secretary-Treasurer - - - Francis E. Mettner
Transwestern Oil Company
605 Union National Bank Building

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka.

LOUISIANA

NEW ORLEANS GEOLOGICAL SOCIETY
NEW ORLEANS, LOUISIANA

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The California Company, 1818 Canal Bldg.
Vice-President and Program Chairman - - - - - - - - - - - - Richard L. Denham
Humble Oil and Refining Company
Secretary-Treasurer - - - - - Philip R. Allin
Gulf Refining Company, Harvey, La.

Meets the first Monday of every month, October-May inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

LOUISIANA

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SHREVEPORT, LOUISIANA

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Carter Oil Company
Vice-President - - - - - - Brame Womack
Sohio Petroleum Corporation
Secretary-Treasurer - - - - - - - J. Ed. Lytle
Union Producing Company

Meets monthly, September to May, inclusive, in the State Exhibit Building, Fair Grounds. All meetings by announcement.

LOUISIANA

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LAKE CHARLES, LOUISIANA

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Secretary - - - - - - - - - Lloyd D. Traupe
Ohio Oil Company
Treasurer - - - - - - - - - D. E. Newland
Magnolia Petroleum Company

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

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Michigan Geological Survey
Capitol Savings and Loan Bldg., Lansing
Vice-President - - - - - Richard H. Wolcott
Sohio Petroleum Company, Mt. Pleasant
Secretary-Treasurer - - - - Charles K. Clark
Pure Oil Company
402 2d Natl. Bank Bldg., Saginaw
Business Manager - - - Kenneth A. Gravelle
Gulf Refining Company, Box 811, Saginaw

Meetings: Bi-monthly from November to April at Lansing. Afternoon session at 3:00, informal dinner at 6:30 followed by discussions. (Dual meetings for the duration.) Visiting geologists are welcome.

MISSISSIPPI

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Mellen & Monsour
Box 2571, W. Jackson Sta.
Vice-President - - - - - - - J. B. Wheeler
Stanolind Oil and Gas Company
Secretary-Treasurer - - - - - - H. L. Spyres
Skelly Oil Company

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

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ARDMORE, OKLAHOMA

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The Texas Company, Box 539
Vice-President - - - - - Paul L. Bartram
Phillips Petroleum Company
Secretary-Treasurer - - - - - - Ben S. Curtis
Independent, Box 156

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

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Carter Oil Company
Vice-President - - - - - - Harold J. Kleen
Skelly Oil Company
Secretary-Treasurer - - - - Frederick H. Kate
Shell Oil Company, Inc.
965 First National Building

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon. Y.W.C.A.

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SHAWNEE, OKLAHOMA

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Atlantic Refining Company

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Atlantic Refining Company, Box 169

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

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1st Vice-President - - - - - Russell S. Tarr
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U. S. Geological Survey

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Ashland Oil and Refining Company

Editor - - - - - - - - Robert F. Walters
Box 661, Gulf Oil Corporation

Meetings: First and third Mondays, each month, from October to May, inclusive at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

TEXAS

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Vice-President - - - - - - Dale L. Benson
Sinclair Prairie Oil Company, Box 480

Secretary-Treasurer - - - - - O. G. McClain
Consultant, 224 Nixon Building

Regular luncheons, every Wednesday, Petroleum Room, Plaza Hotel, 12:05 P.M. Special night meetings, by announcement.

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DALLAS, TEXAS

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Magnolia Petroleum Company, Box 900

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DeGolyer and MacNaughton, Continental Building

Secretary-Treasurer - - - - John M. Clayton
Seaboard Oil Company, 1400 Continental Building

Executive Committee - - - - Fred H. Wilcox
Magnolia Petroleum Company

Meetings: Monthly luncheons by announcement. Special night meetings by announcement.

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Humble Oil and Refining Company

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Continental Oil Company
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Luncheons: Each week, Monday noon, Blackstone Hotel.
Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

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The Texas Company, Box 1720

Secretary-Treasurer - - S. K. Van Steenbergh
Sinclair Prairie Oil Company
901 Fair Building

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

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Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

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Vice-President - - - - - - Lynn L. Harden
Sinclair Prairie Oil Company

Secretary-Treasurer - - - - - Turner Wynn
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Luncheons and evening programs will be announced.

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Vice-President - - - - - - Marion J. Moore
Transwestern Oil Company, 1600 Milam Building

Secretary-Treasurer - - - - - Paul B. Hinyard
Shell Oil Company, Inc.
2000 Alamo National Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

WEST TEXAS GEOLOGICAL SOCIETY

MIDLAND, TEXAS

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Consulting, Box 1385

Vice-President - - - - - - W. J. Hilseweck
Gulf Oil Corporation, Box 1150

Secretary-Treasurer - - - - Charles A. Shaw
Forest Oil Corporation, Box 366

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605 Union Building

Editor - - - - - - - - - - J. D. Castner
Box 1433

Meetings Second Monday, each month, except June July, and August, at 6:30 P.M., Kanawha Hotel.

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General Petroleum Corporation

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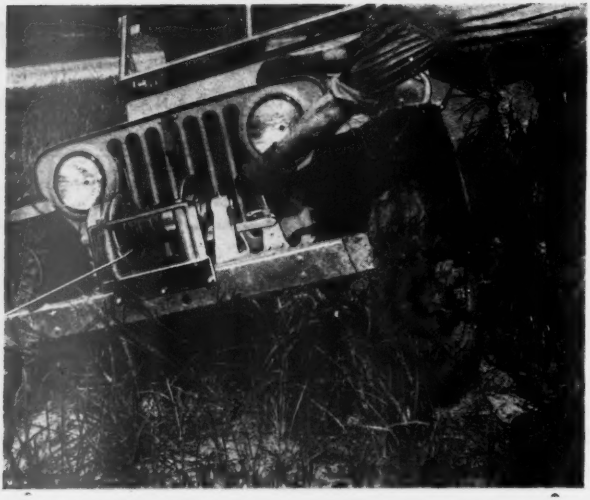

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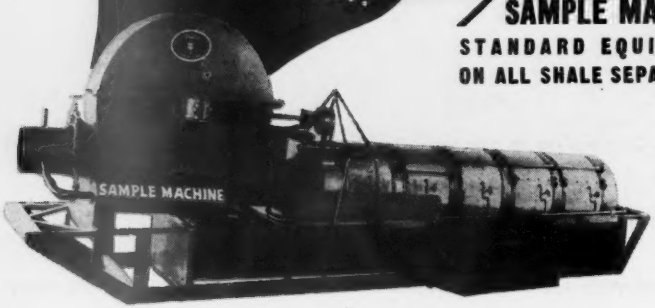

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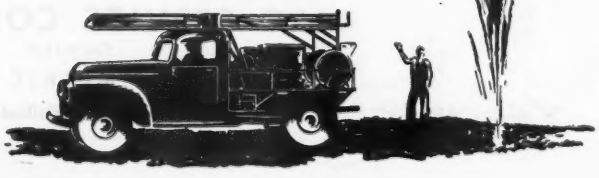

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Announcement

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is made of the opening of a permanent business office for the Society, with Mr. C. C. Campbell as Business Manager, effective July 15, 1946. All correspondence other than editorial matters (Dr. L. L. Nettleton, Editor, 1348 Esperson Bldg., Houston 2, Texas) should be addressed to

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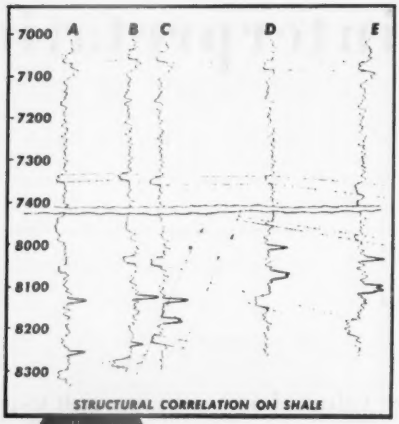

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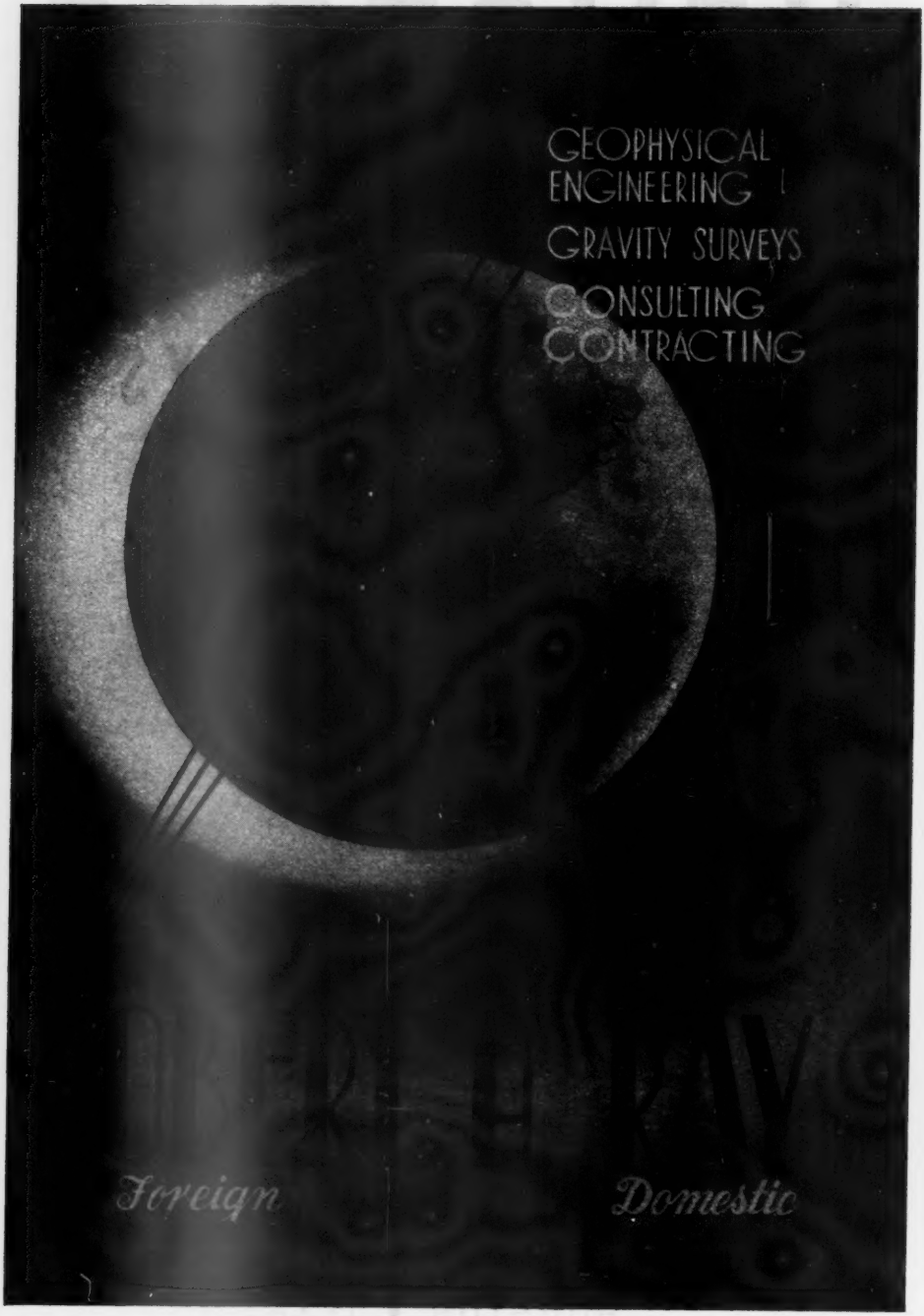
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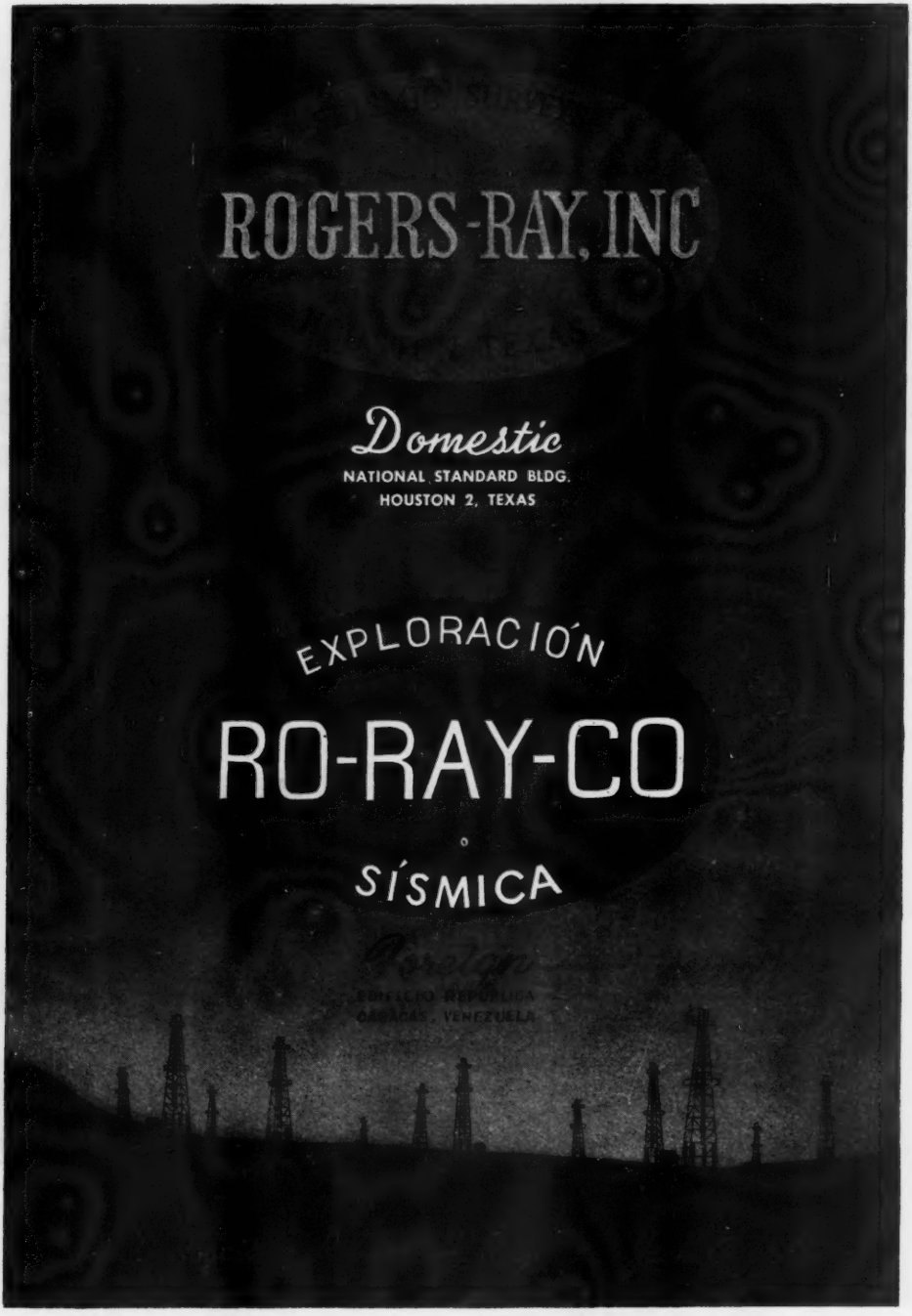
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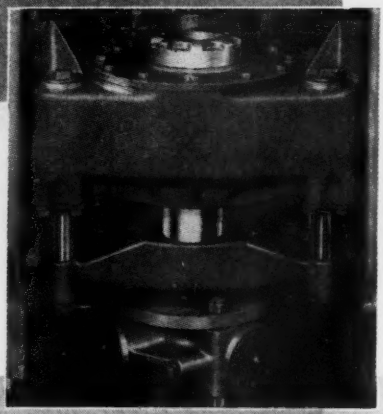

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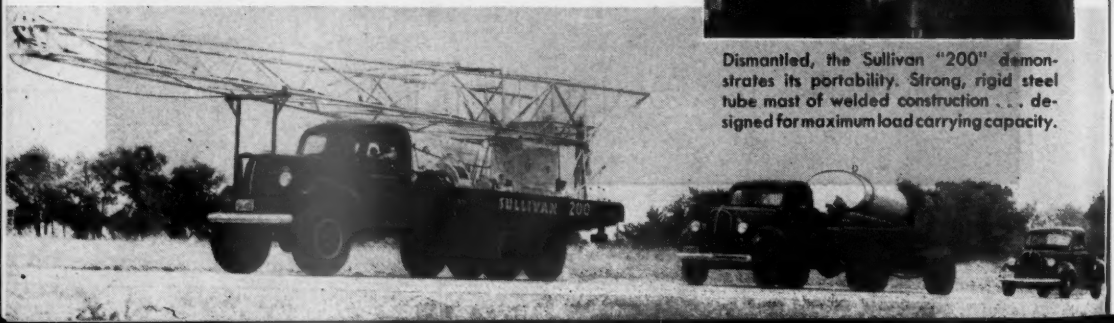

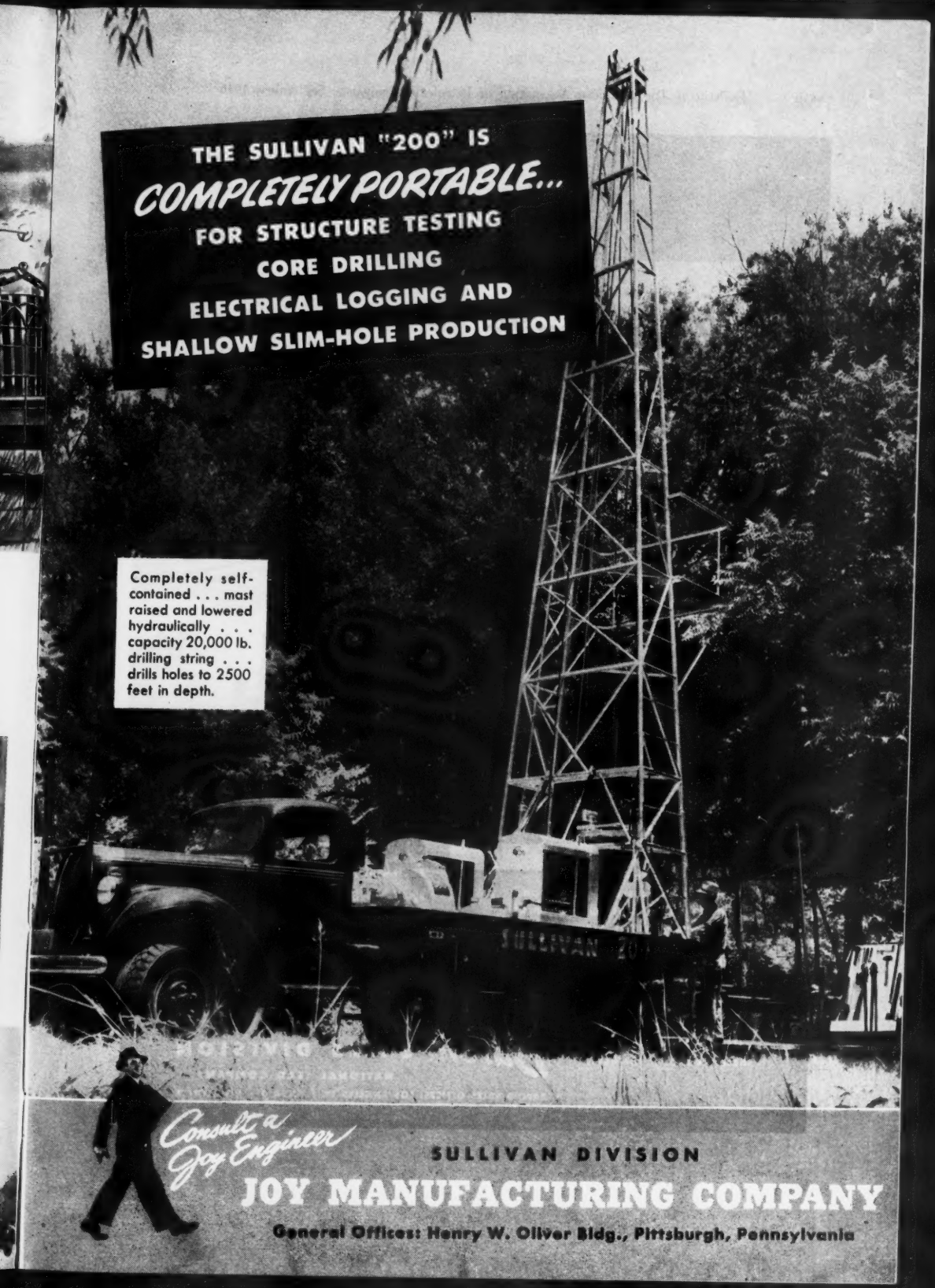
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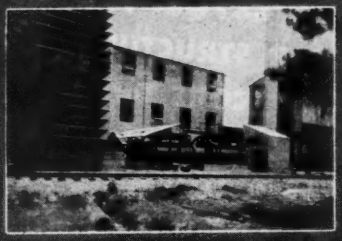

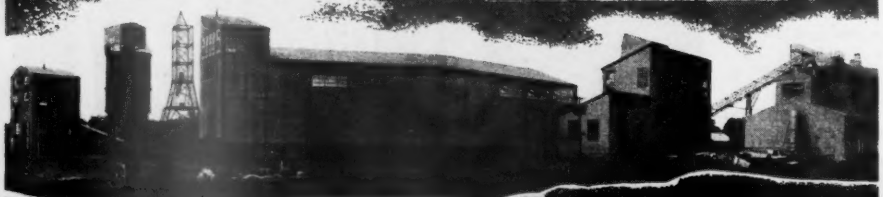

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Last of a series of advertisements featuring our mine and mill facilities

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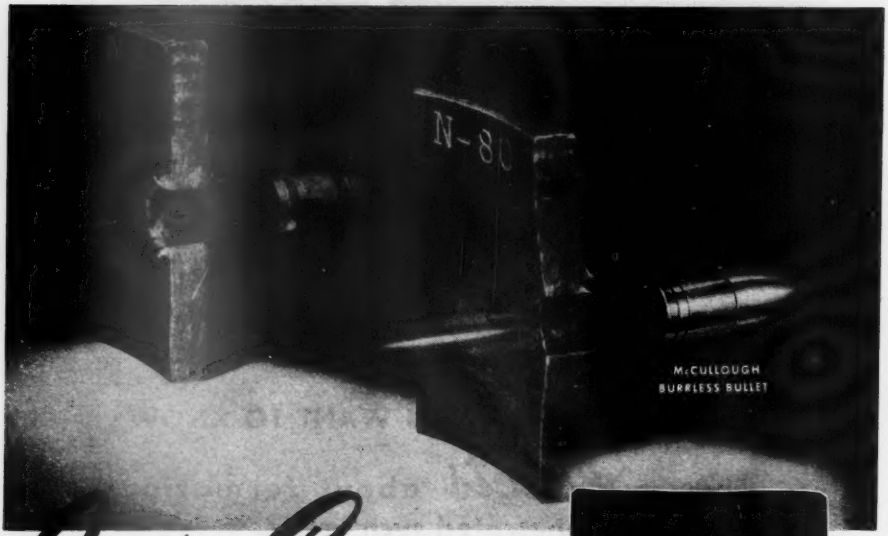
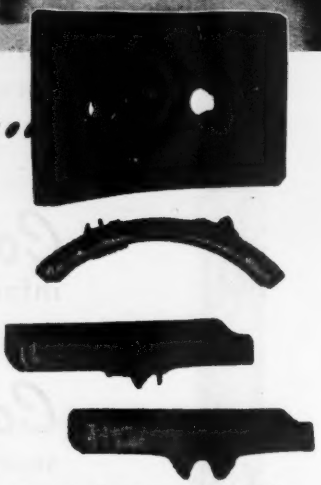


Just Compare...



The unretouched photographs reproduced here show a section cut from 7⅝" 39 lb. N-80 casing which was gun-perforated, at the same instant, under identical conditions, by regular bullets and by the new improved McCullough Burrless Bullet . . . one of a series of tests which have proved beyond question that *McCullough's Armor-Piercing Burrless Bullet not only gives a completely burr-free hole, but also gives slightly more penetration into the formation!*

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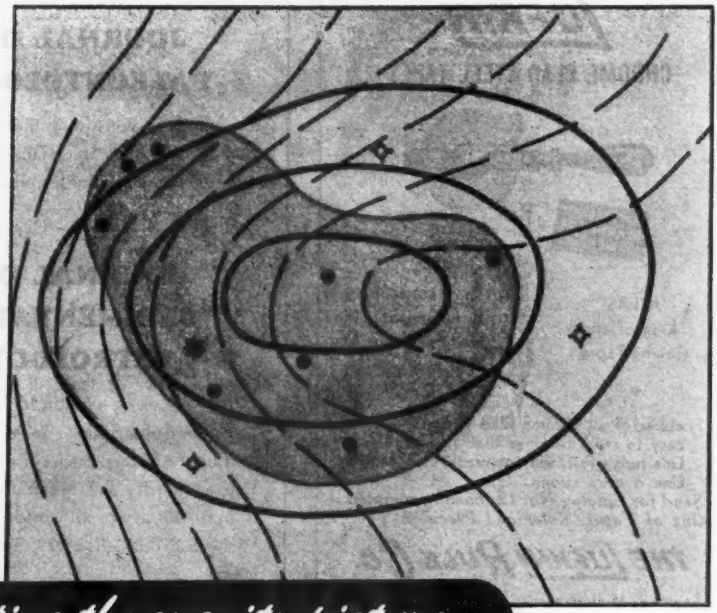

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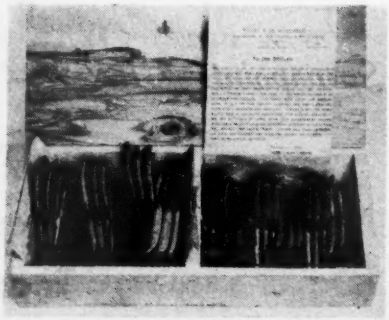

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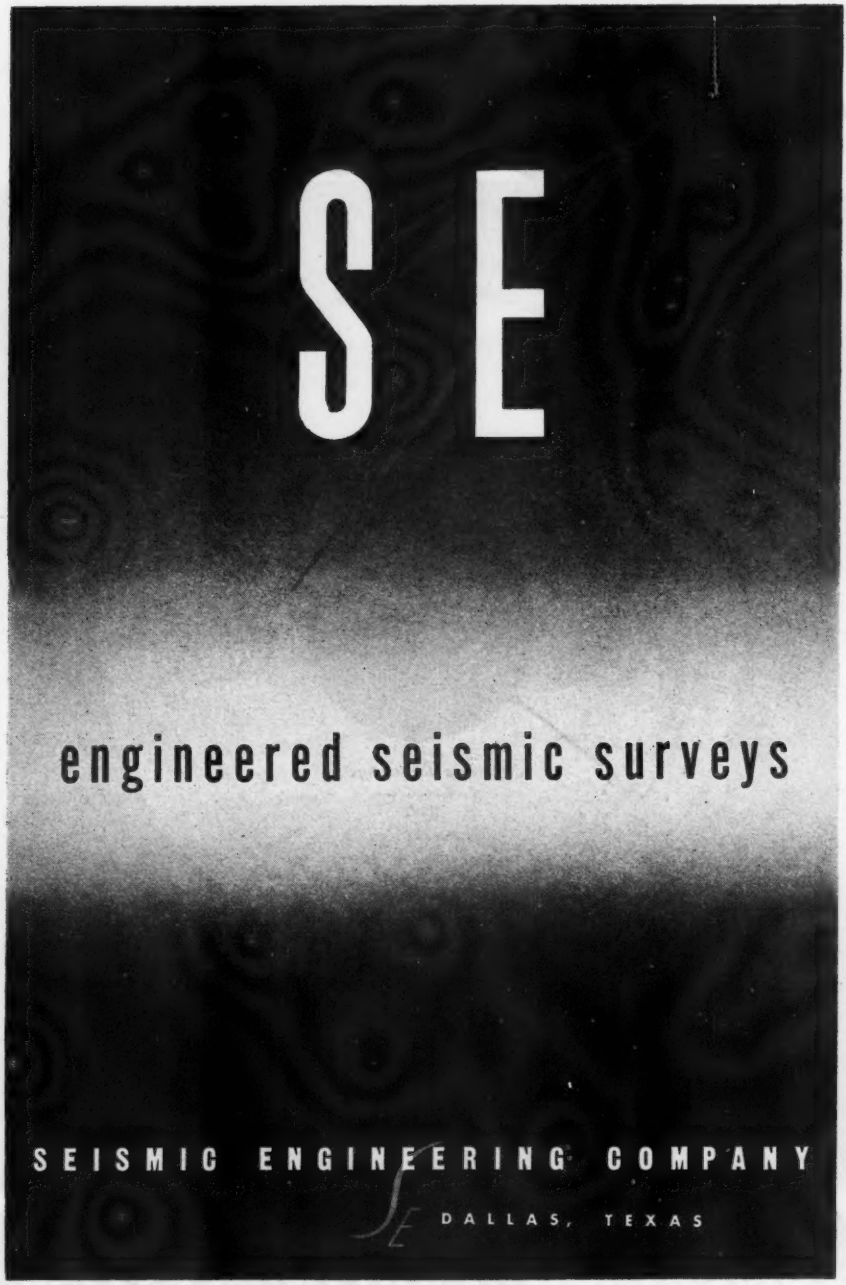
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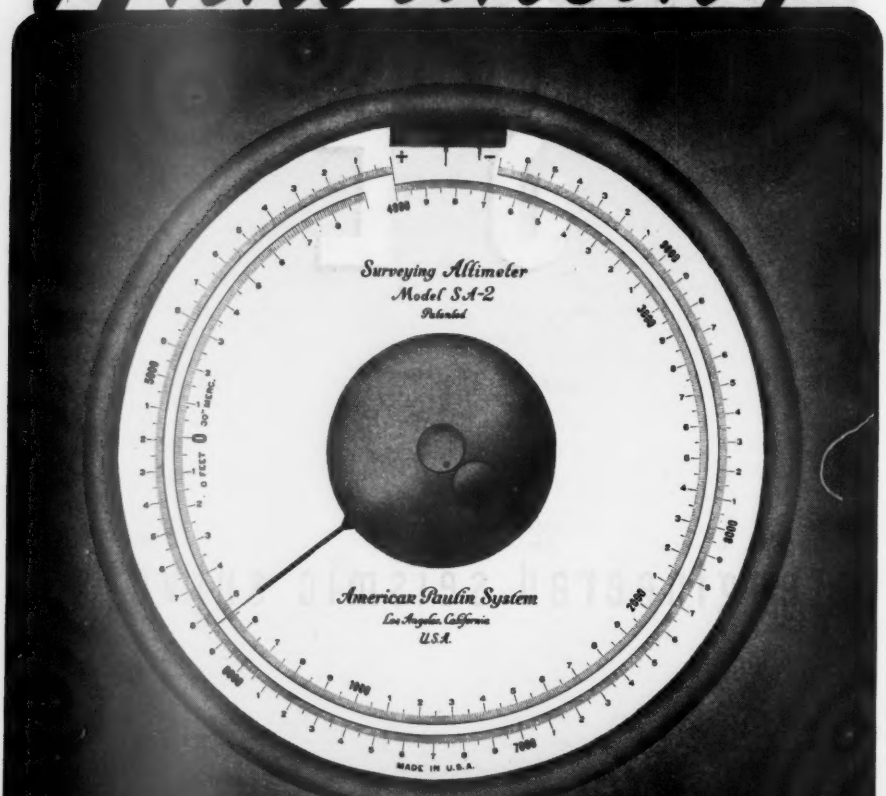

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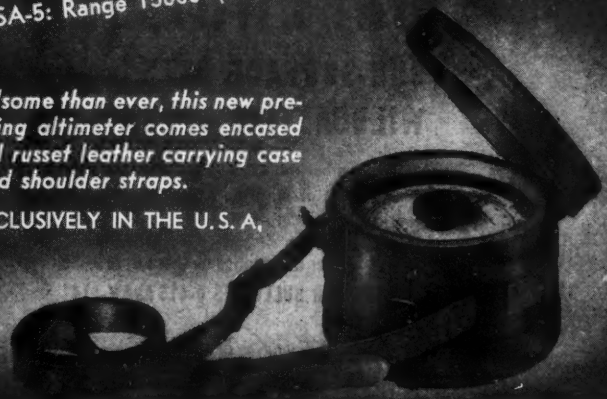

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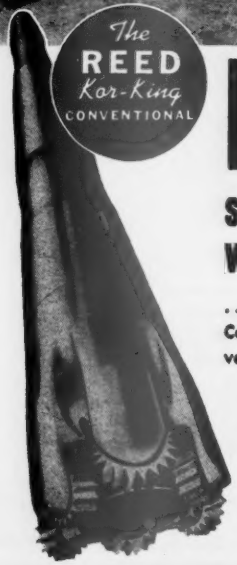

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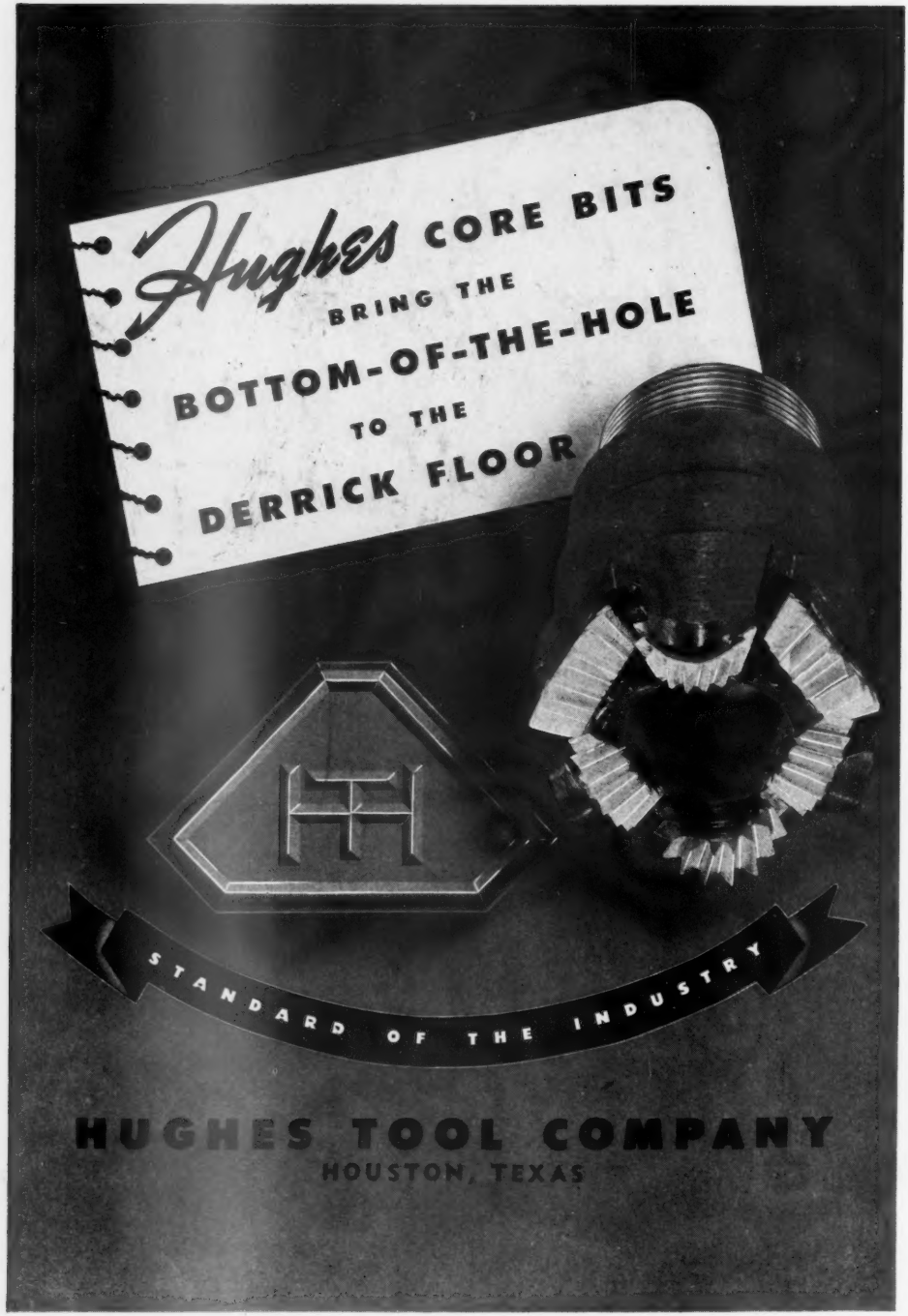
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